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# THE TECHNOLOGY OF MANNED RETURN FROM OUTER SPACE *

BY

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Mr. LePage, Dr. Burlew, Mr. Redding, Members of The Franklin Institute and Guests, I accepted Dr. Burlew's invitation to deliver the Redding Lecture this evening with great enthusiasm. First, because it is a great honor to address the members of one of America's oldest and finest scientific institutions. Secondly, it is another contribution to the fine relationship enjoyed between The Franklin Institute and my firm, the General Electric Company, and, pertinent to this evening's subject, this relationship has included one of America's first space technology programs, a joint Franklin Institute–General Electric project to obtain the nation's first outer space data with the V-2 missile in 1947. And thirdly, this Redding Lecture, endowed on behalf of Charles Redding, one of our nation's foremost research and development pioneers, provides an excellent platform to discuss the opportunity our nation has to lead in manned flight in space, by the application of existing technology, gained on current missile programs.

Space technology is now in a period of explosive development; today we are well along on the phase of the instrumented satellite. Dr. Stever, in his recent talk here at the Institute, told of the national plans for promotion of this development. The next step in space technology is clearly the manned satellite—and this step is imminent!

A program for manned flight into, and return from, outer space is now beginning under the "can-do" leadership of the new National Aeronautics and Space Administration. They have just issued invita-

* The Charles S. Redding Lecture, delivered at the Stated Meeting of the Institute held Wednesday, November 19, 1958, in the Lecture Hall.

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tions for industry to propose on the first manned satellite capsule—these invitations coming only twenty-one days after formal establishment of this new agency. The specifications on this proposal call for a manned satellite capsule of about 2000 pounds, to orbit 120 miles above the Earth, and to re-enter safely after several passes around the Earth. The principal purpose of the flights will be to study man's reaction and adaptability to an extended period of the weightless space environment.

The feasibility of such flights within a two-to-three-year period is without question, based on the technology existing today from our nation's ballistic missile programs. For example, the re-entry problem, of dominant concern for manned return from outer space, is now well understood as the result of work we in General Electric have done for the Thor and Atlas ballistic missiles.

Our team of 600 scientists and engineers, working on this problem here in Philadelphia, has had considerable success in the research and development of vehicles to carry warhead payloads up to 700 miles in space and safely back through the re-entry environment. Figure 1

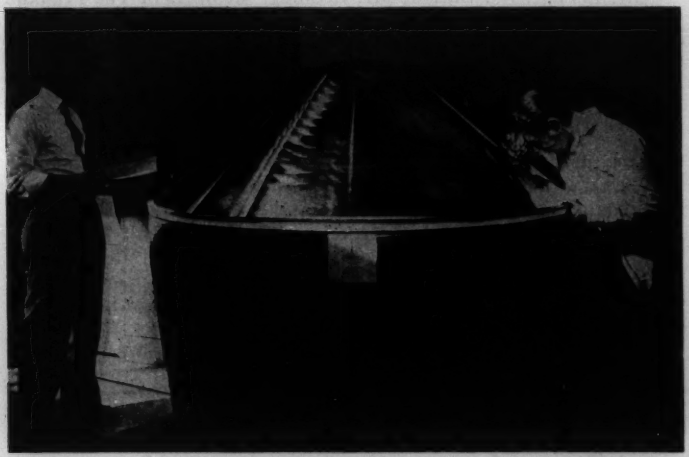

FIG. 1.

shows the nose cone design for the first operational Thor IRBM and Atlas ICBM missiles. You will notice the familiar blunt shape that has been required in our first designs for survival of re-entry. Enclosed within the forward end of the missile is an afterbody, the shape of which is still classified; but within the limits of security, I can say that it would be possible to carry a man within this nose cone re-entry vehicle, although this is not the optimum design for manned re-entry. The

development of this ICBM nose cone has been an enormous engineering undertaking. Technical progress has been extremely fast, and we owe a great deal to the many dedicated men of the Air Force–Industry team who have contributed to that progress. By their efforts, we have learned how to survive temperatures greater than the surface of the sun, and now have available essentially all the technological know-how required for man's initial return from space.

One of the tools most useful in our development of re-entry technology is the large plasma arc shown in Figs. 2 and 3. Figure 2 is a

FIG. 2.

schematic of our large air arc showing a nose cone model being tested, and Fig. 3 is an actual photo of one of the arcs in operation. This General Electric facility, the largest such in the free world, permits us to approach, in the laboratory, the major aspects of the re-entry heating environment, with available testing temperatures over twice as hot as the surface of the sun.

Numerous ballistic missile flight tests have confirmed the design results anticipated by our scientists and engineers through the use of this arc facility, our other experimental equipment, and through our theoretical investigations. One of the flight programs was Project Able, in which the nose cone survived re-entry at 6000 miles range, giving

valuable experimental design data. Figure 4 shows the nose cone ready for launch on the Thor-Able vehicle.

With this experience, and with our record of success with inanimate payloads, we now have the data needed for the tailoring of re-entry vehicles as carriers of man. Design studies on a manned version of our nose cones have been under way in our Department for over two years.

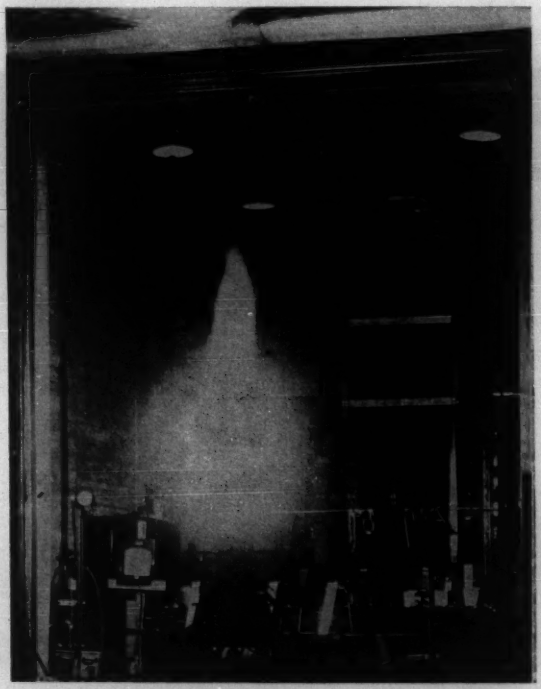

FIG. 3.

We have detailed several design approaches and have constructed metal mock-ups of some of these designs.

Figure 5 shows the interior of a design that has been outfitted in detail. The aft-end cover has been removed so that you can see inside. Note the seat which is molded to fit each pilot individually; note also his instrument and control panel. Figure 6 shows the external configurations of other designs we've studied.

I would like to discuss with you some of the details of how the re-entry design problem will be effected as we make the substitution of a man, instead of a warhead, as the re-entry vehicle payload.

The most severe aspects of the re-entry environment are the heating and acceleration (see Fig. 7). These must be reduced from the missile design levels for survival of a man in re-entry. Both of these factors are strongly dependent on the re-entry trajectory, particularly the path angle or degree of steepness of the trajectory. The peak heating rate during re-entry is minimum for shallow entry angles, although this

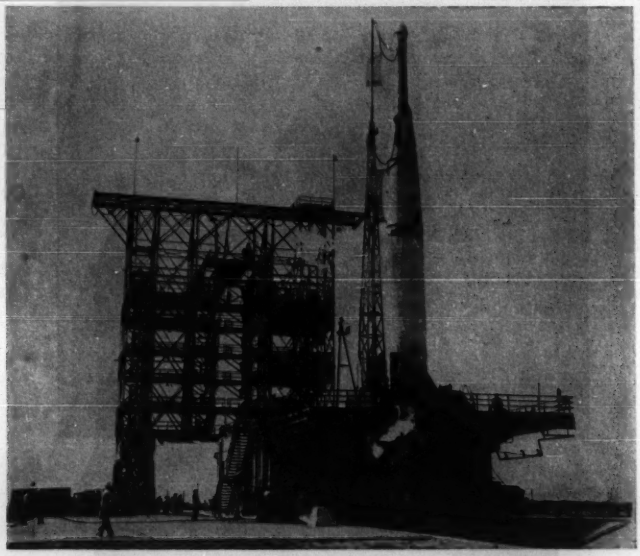

FIG. 4.

condition gives rise to a maximum amount of total heating; but the limiting factor is re-entry acceleration, which is minimized by providing a shallow re-entry angle. Heating also is more severe for high ballistic parameters, or low drag bodies, while the acceleration is essentially independent of this parameter. Thus, compared to unmanned re-entry vehicles, manned re-entry vehicles will have higher drag shapes, and will be guided for re-entry into the Earth's atmosphere at much more shallow angles, this approach being the best compromise of the heating and acceleration limits.

As I noted before, the re-entry acceleration, or the rate at which

FIG. 5.

FIG. 6.

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FIG. 7.

the vehicle slows down upon initial entry into the atmosphere, is limited by the capability of man to stand this acceleration force without serious physiological damage. The curves in Fig. 8 are experimental data on man's tolerance to acceleration impulses; if the high g field lasts as long

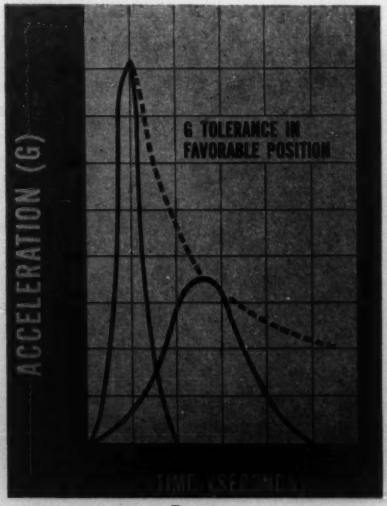


FIG. 8.

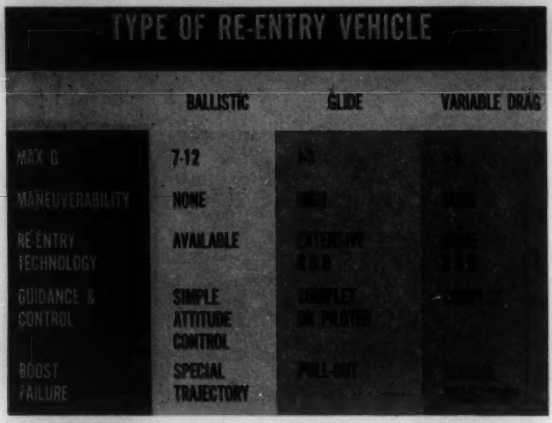


FIG. 9.

as a minute, ten to twelve times the force of gravity is generally considered a practical limit of human tolerance, for a man properly oriented and supported.

We have considered three alternate concepts for manned re-entry vehicles—pure ballistic, glide and variable drag vehicles (see Fig. 9).

FIG. 10.

Each of these has its own advantages, and there is little doubt of the ultimate benefit of glide and variable drag vehicles from the standpoint of providing a maneuvering capability. But there is not yet any assurance that a pilot can control such a vehicle in the space and re-entry environment. The best way to get this assurance, and incidentally, the fastest way to get a man into space and back, from the point of view of the fastest hardware development schedule, and the highest reliability and safety, is by use of a purely ballistic vehicle for the initial flights into space. The ballistic vehicle does have the disadvantage of higher accelerations, on both re-entry and emergency es-

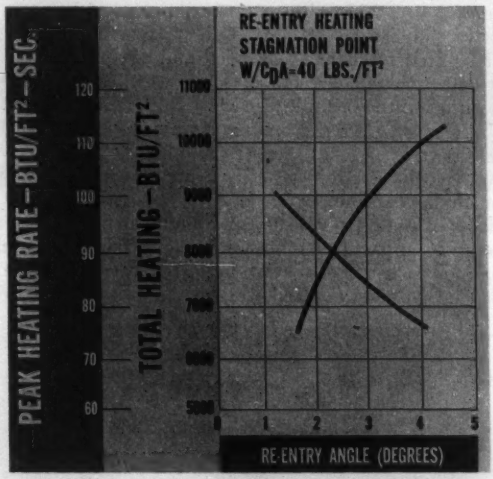


FIG. 11.

cape during launch. However, these higher g's are within tolerable limits, and we have selected for the basis of our design studies, the simple pure ballistic shape.

The technical information to follow in this lecture concerns our ballistic selection. You can see from Fig. 10 how the acceleration builds up during re-entry and how it is influenced by the angle of re-entry. A re-entry angle of somewhat less than 3 degrees from the horizontal would be chosen to limit the peak acceleration to about 12 g's.

The re-entry heating for a typical design is shown in Fig. 11 as influenced by the re-entry angle. For an angle of 3°, the total heating at the nose is 7500 Btu per square foot and the peak rate of heating is 100 Btu per square foot per second. You can see that we have quite a severe design condition to shield the occupant from this heating.

FIG. 12.

Manned flight in space will initially be in a nearly circular orbit at an altitude of 100 to 125 miles and a speed of 25,500 feet per second. To get out of the circular orbit in order to return to Earth, a retro-rocket will be fired to change the speed and direction of the satellite. One way to start this vehicle out of orbit is to fire the retro-rocket in direct opposition to the orbital velocity. But we have found that it is more advantageous to fire the retro at an angle inclined to the orbital velocity, as shown in Fig. 12. The proper choice of the retro-rocket for its imparted velocity capability and the proper inclination angle when fired are of fundamental importance.

The effects of the retro velocity and angle, as influencing the range from retro-fire to impact, have been studied and are shown in Fig. 13. We see that for each value of retro-imparted velocity, there is an inclination angle that gives minimum range and also minimum dispersion

FIG. 13.

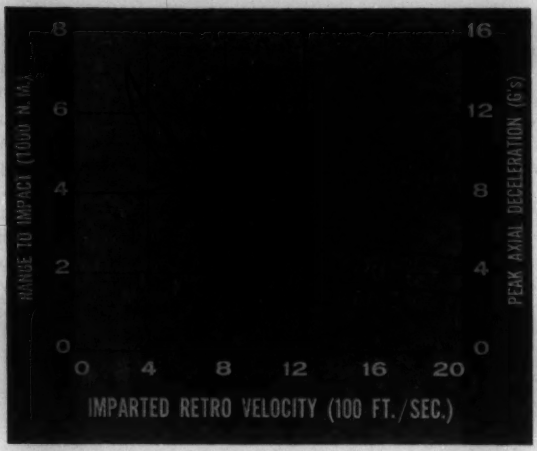
RANGE TO IMPACT (1000 N. MI.)
PEAK AXIAL DECELERATION (G's)
0
2
4
6
8
0
4
8
12
16
20
IMPARTED RETRO VELOCITY (100 FT./SEC.)

FIG. 14.

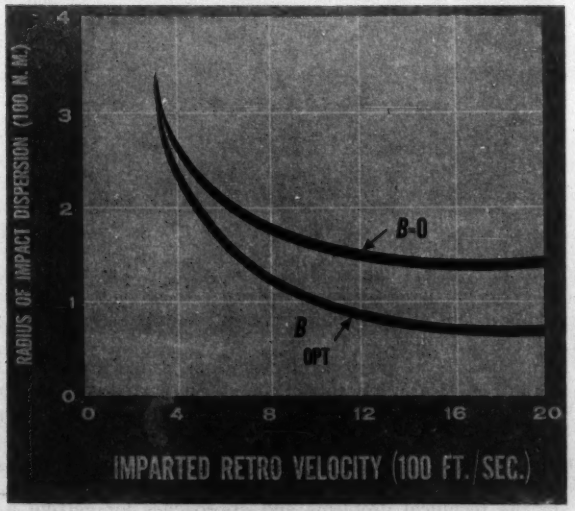
RADIUS OF IMPACT DISPERSION (100 N. MI.)
0
1
2
3
4
B-0
B
OPT
0
4
8
12
16
20
IMPARTED RETRO VELOCITY (100 FT./SEC.)

FIG. 15.

of the impact point. This angle is called B optimum and is of major significance in the design for manned return from space.

The size of the retro-rocket in terms of imparted velocity, influences the range to impact, and the peak acceleration, as shown in Fig. 14. As the retro-rocket gets larger, so do the peak g's. But the range and with it, the dispersion, diminish. To get some feeling for the limits within which we must work, you will recall that a 12-g peak on a well-supported man is uncomfortable but tolerable, on the basis of today's physiological data. This tells us not to exceed 1500 feet per second imparted velocity for return from orbit. The lower limit on velocity will be set by the maximum range to impact and dispersion area that can be tolerated and still have an assured successful location and recovery of the

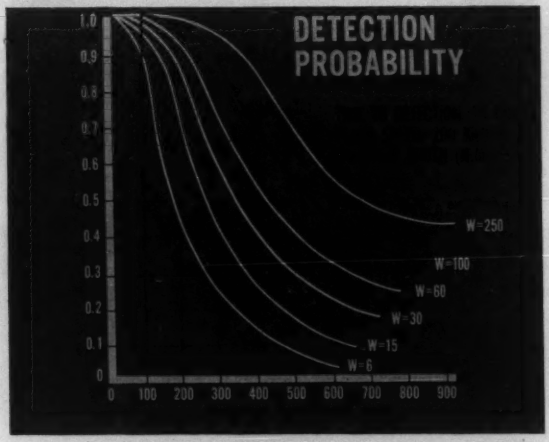


FIG. 16.

vehicle and occupant. Our studies show that at this allowable 1500 feet per second imparted velocity, the range to impact would be 2000 nautical miles, and the dispersion about the intended impact point would be about 75 miles.

In summary, the re-entry acceleration and range from retro firing are shown in Fig. 15 as a function of time for imparted velocities of 300 and 1500 feet per second, oriented at B optimum as described earlier. After experiencing this acceleration and traveling this range, final descent to Earth will be by a parachute system, much like the parachutes currently in use for return of unmanned re-entry vehicles. So, these are the technical problems and approaches for getting a man safely from space to the Earth's surface.

That leaves us with the important mission of locating the man and recovering him. The techniques employed here will be quite similar to those we now use for re-entry vehicles and for our data-recovery capsules. We would plan to use ships and planes for search and location, aided by radio beacons, optical beacons and other location aids as at present. Figure 16 shows the probability of recovery within 24 hours for various impact dispersion and search systems.

The current state of the art will permit impact dispersion of less than 100 miles, as we have shown, and search-sweep widths of more than 100 miles. On this basis, you see that there is an extremely high probability of successful location of the capsule and its occupant within 24 hours after return to Earth.

FIG. 17.

FIG. 18.

We have made an interesting study of launch direction and orbit orientation. As you know, most launches from Cape Canaveral are made in a southeastern direction. This is true because the range is laid out with range stations in that direction and a long expanse of open ocean is available. To launch in another direction would require new range facilities and re-orientation of the missile guidance stations. However, this may be well worth the expense because, as we see in Fig. 17, a launch southeast from Cape Canaveral gives only two orbital paths in the vicinity of the United States in the early part of the orbital history. On the other hand, a launch in the northeast direction would put the first six or seven orbital cycles in the vicinity of the United States (see Fig. 18). There would be considerably more possibility for a landing on or near the United States, thus greatly facilitating the search and recovery problem.

We feel that the problems of location and recovery are well in hand. The success of similar operations in our ballistic missile programs is just cause for such confidence. We have repeatedly performed success-

ful flight-data recoveries with our data-recovery capsule. In one such recent operation with an Atlas ICBM missile, our nose cone carried a plastic spherical ball which contained a tape recorder on which data were recorded during flight. Late in re-entry, this capsule was ejected from the nose cone, survived impact on the ocean's surface and remained afloat until recovered. To aid in location by search aircraft and ships, the capsule carries several location aids—a radio beacon, a SOFAR bomb, fluorescent dye markers and flashing lights. It also includes shark repellant because we have found that sharks are attracted to the capsule as it bounces about on the surface of the water.

FIG. 19.

The principal key problem yet facing us in preparation for man's first venture into outer space is that of reliability and safety of the pilot. Thus the design approach taken will be one to emphasize man's safety. The basic simplicity requirement (see Fig. 19) is typified by the choice of the purely ballistic type of vehicle, the simplest approach possible, and the type currently in use for the ballistic missile programs.

The Atlas missile will very likely be chosen to boost the manned satellite into orbit. With the large number of Atlas flights scheduled in the next year and a half, the Atlas should be very well proven in flight before the first effort to launch a manned satellite. We expect no new development of a booster system, with the frustration of failures inherent in new booster developments.

In every possible area, components will be used that have been proven successful and reliable through our current nose cone programs.

FIG. 20.

And where components themselves are not directly applicable, proven techniques, approaches and technologies will be applied.

A stringent program of qualification and reliability testing will be conducted prior to the first launch of man into orbit. The pre-flight test program, with drop tests, impact tests, environmental tests and many others, will be more stringent than on any program of the past or present. Early ballistic, non-orbiting flights, unmanned and with small animal life, will be made to prove out the entire system. Initial flights into orbit will probably be with complete, but unmanned, satellite

USEFULNESS OF MANNED SPACE FLIGHT
• Determination / Development of Man's Capability in Space
• Scientific Research—Earth's Environment
• Space Exploration and Research
• Earth and Space Reconnaissance
• Space Defense

FIG. 21.

systems. All this effort is directed to achieve maximum reliability and safety.

An example of the emphasis on safety of the man is seen in Fig. 20, a proposed satellite design recently released by the National Aeronautics and Space Administration. To the basic vehicle design has been added a dual parachute system, one backing up the other, to provide assured safe final descent; the entire forward pylon structure is added to carry the escape rocket used to get the capsule out of the vicinity of the missile booster, in the event of a failure of the missile during launch. Such attention to crew safety will be a fundamental requirement for this program.

A question we are often asked about our enthusiasm for manned space flight is "What use is it, why do it?" There are several important reasons for this mission (see Fig. 21): first, and most important as a first step, is the determination and further development of man's capability to survive and function in the space environment. Until this objective is accomplished, all other considerations of manned flight in space are purely academic. Having shown man's capability, then we can go forward to more advanced space missions of research, exploration, reconnaissance and defense. For those who cannot foresee the possibilities that are opened by man's venture into space, I am reminded of an anecdote told of Benjamin Franklin. One hundred seventy-five years ago, while observing early balloon flights in Paris, a skeptic asked "What good could a balloon be?" Franklin is said to have replied, "What good is a new-born baby?" That's how we feel about the birth of the age of "man in space."

In conclusion, I have tried to show you that manned flight in space is more than just "within the present state of the art." Almost all of the technology has been proven, most of the hardware is available, and the remaining parts of the system are in the design stage. Only modest steps are required, those of orienting the design to the parameters dictated by the human occupant. These steps will be taken rapidly. We must now set our sights to the technologies required for flight beyond Earth orbits.

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# SOME THERMODYNAMIC PROPERTIES OF A MAPPING

BY

DAN E. CHRISTIE[1]

ABSTRACT

It is usual to represent equilibrium states of a simple thermodynamic system by points in the $Pv$ plane and in the $Ts$ plane. In this article attention is focused on the natural correspondence thus established between points of these planes. This correspondence induces topological transformations on point sets, isometric transformations on areas, and projective transformations on slope ratios. Each of these cartographic points of view produces results of thermodynamic significance. In particular the conclusions on slope ratios provide a general view of the concepts of specific heat capacity and bulk modulus. Interesting geometric constructions relating these concepts are developed.

## INTRODUCTION

It is often instructive to examine a familiar subject from an unaccustomed point of view. In this article certain aspects of elementary thermodynamics are explored. The point of view adopted is essentially that of cartography or map-making. Reference is made to elementary ideas from branches of mathematics not often used in physics: to topology and projective geometry.[2] The purpose of this inquiry is to study at an elementary level relationships between mathematical and physical aspects of a basic thermodynamic situation. Section I sketches the topological foundations. Here both mathematical and physical properties are too familiar to be startling but too important to be omitted. Section II shows best the interplay of disciplines: the first law of thermodynamics requires preservation of areas under certain transformations, but this purely mathematical restriction leads back to central thermodynamic identities. In Section III the study of slope transformations permits an analysis of just what is meant by generalized specific heats and bulk moduli. Here the mathematical framework is that of projective transformations. A convenient consequence is the possibility of constructing a nomograph relating corresponding values of bulk modulus and specific heat by a simple central projection. Perhaps the most interesting specific conclusion is the expression of generalized specific heat by a ratio formula based on the usual $c_P$ and $c_v$. A geometric representation of this relationship appears in a construction reminiscent of the circle diagrams used in geometric optics to represent the law of refraction.

It is not expected that the methods or point of view of this article will

[1] Department of Physics, Bowdoin College, Brunswick, Maine.

[2] Recently a fruitful application of topology to thermodynamics has been made by Landsberg. See P. T. Landsberg, "Foundations of Thermodynamics," *Rev. Modern Phys.*, Vol. 28, p. 363 (1956).

be adopted in courses on thermodynamics. It is rather hoped that teachers and students of the subject will find some pleasure in meeting unorthodox interpretations and some amusement in following through arguments and constructions touching a number of mathematical fields.

### I. EQUATIONS OF STATE: MAPPING OF POINTS

Let us consider a simple system whose thermodynamic state can be specified by the coordinates pressure, $P$, and specific volume, $v$. These coordinates are conjugate in the sense that the product $Pv$ has the dimensions of energy per mole, that is, specific energy. For such a system the coordinate pair $(P, v)$ determines uniquely an equilibrium state. It is customary to exploit the fact that this same coordinate pair determines a point, taking the first coordinate as ordinate, in the $Pv$ plane. This circumstance enables us to portray equilibrium states directly by points in a graphical representation. In such a representation related states lead to related points. For instance the points associated with an absolute temperature $T$ lie on an isothermal curve in the $Pv$ plane. Complete cycles of thermodynamic processes are represented by closed curves. It should be understood that not every point in the $Pv$ plane corresponds to a state of the system. We shall consider as suitable only portions of the positive quadrant in the $Pv$ plane for which the system retains the postulated simple behavior.

For a thermodynamic system such as we have introduced, the point-in-a-plane representation can be achieved in several ways. One can use the $PT$ plane, the $vT$ plane, or others involving additional coordinates of state. Here we shall assume that specific entropy $s$ has been defined and that $T$ and $s$ are conjugate coordinates: the product $Ts$, like $Pv$, has the dimensions of energy per mole. An equilibrium state can be represented by the pair $(T, s)$ as well as by $(P, v)$. Given a particular suitable coordinate pair $(P_0, v_0)$, there corresponds a unique suitable coordinate pair $(T_0, s_0)$, and vice versa. This implies that to each suitable point in the $Pv$ plane there corresponds a unique point in the $Ts$ plane, and to each suitable point in the $Ts$ plane corresponds a unique point in the $Pv$ plane. This one-one correspondence of suitable points constitutes a *transformation* or *mapping* of the suitable part of the $Pv$ plane into the $Ts$ plane, and conversely. For example, for an ideal gas with constant heat capacities, to the point $(P, v)$ corresponds the point $(T, s)$ given by the equations

$$T = (1/R)Pv \tag{1}$$

$$s = c_v \ln P + c_P \ln v, \tag{2}$$

where $c_v$ and $c_P$ are the specific heat capacities at constant volume and constant pressure, respectively. Or for blackbody radiation,

$$T = aP^{1/4} \tag{3}$$

$$s = bP^{3/4}v \tag{4}$$

where $a$ and $b$ are constants. (In this example it will be more comfortable to interpret $s$ and $v$ as absolute rather than specific quantities.) In general, for the sort of system we are studying, the transformation is described by equations of the type

$$T = T(P, v) \tag{5}$$

$$s = s(P, v). \tag{6}$$

Since the transformation is one-one, there is no ambiguity in considering the inverse transformation

$$P = P(T, s) \tag{7}$$

$$v = v(T, s). \tag{8}$$

We shall assume that these functions and their inverses are continuous.

Transformation equations such as Eqs. 5 and 6 are usually called *equations of state*. In the case of an ideal gas, Eq. 1 is often called *the* equation of state while Eq. 2 is called an entropy formula.

Thus far we have considered the mapping given by Eqs. 5 and 6 as a point by point mapping. It is interesting to examine its significance for sets of points. Consider for an ideal gas the set of points in the positive quadrant of the $Pv$ plane which satisfy the equation

$$T_0 = (1/R)Pv \tag{9}$$

for a particular constant value $T_0$. These points, lying on the familiar isothermal hyperbola, are all mapped onto the positive part of the line with equation

$$T - T_0 = 0, \tag{10}$$

in the $Ts$ plane. Similarly the adiabatic locus having the equation

$$s_0 = c_v \ln P + c_P \ln v \tag{11}$$

is mapped into the line with equation

$$s - s_0 = 0. \tag{12}$$

Now the cartographic aspect of the problem begins to appear. We are dealing with a map-making procedure which represents adiabatic and isothermal curves by straight lines, as is sketched for an ideal gas in

Fig. 1. Similarly the inverse mapping represents isobaric (constant pressure) and isochoric (constant volume) loci in the *Ts* plane by an orthogonal network of lines in the *Pv* plane. What properties are unchanged by these transformations? As long as the mapping and its inverse are continuous and one-one, as we have assumed, we can be sure at least that the mapping preserves topological properties such as connectedness.[3] Processes represented by arcs in the *Pv* plane will be similarly represented in the *Ts* plane. A simple curve will map onto a simple curve, as diagrammatic treatments of the Carnot cycle always show. These basic properties are not surprising because they are normally taken for granted.

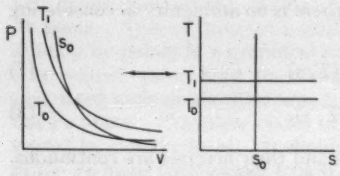


FIG. 1. Topological mapping of loci (for an ideal gas).

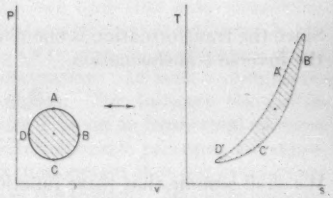


FIG. 2. Isometric (area-preserving) mapping of regions.

The sort of map-making problem which we consider is not an unusual one for cartographers. Instead of making a map of actual terrain, we are really talking about a map of a map. Thus the *Pv* representation of a simple thermodynamic system is itself a map of thermodynamic behavior, complete with lines of constant temperature, constant entropy, constant volume, constant pressure and so on. The *Ts* representation is then a map of the *Pv* representation. It is not a simple geometric projection such as cartographers use, but a realignment or deformation dictated by physical equations of state.

Whenever one confronts a map-making procedure, one is interested in the intelligibility of the new representation. What happens to areas? What happens to directions? These matters are considered in Sections II and III. It will henceforth be assumed that mappings are differentiable as well as continuous and one-one; so the conclusions will apply primarily to homogeneous systems.

## II. ENERGY CONSIDERATIONS: MAPPING OF AREAS

It is apparent from Fig. 1 that the mapping we consider introduces distortions, even though topological properties are preserved. Probably the most important property of the transformation is that it is isometric (area preserving). Areas in the *Pv* plane and *Ts* plane both represent

[3] For a summary of topological concepts, see for instance Solomon Lefschetz, "Introduction to Topology," Princeton University Press, 1949, Chapter I.

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energy per mole; so preservation of areas has basic physical significance. Consider in the $Pv$ plane any region bounded by a simple closed curve. As was remarked in Section I, this region maps onto a $Ts$ region also bounded by a simple closed curve, as indicated roughly in Fig. 2. Taking these curves, clockwise, to represent a thermodynamic cyclic process, one has as an interpretation of area in the $Pv$ plane:

$$\oint P dv = (\text{area})_{Pv} = \text{work done by system.} \tag{13}$$

And similarly in the $Ts$ plane one has

$$\oint T ds = (\text{area})_{Ts} = \text{heat absorbed by system.} \tag{14}$$

But for a cycle, by the first law of thermodynamics, these quantities are equal; so the areas are equal. This statement assumes that consistent units are used. Under the circumstances described the analytic condition for conservation of area may be expressed by the assertion: the Jacobian of the transformation must equal unity.[4] That is, if the transformation is expressed by Eqs. 5 and 6, it must follow that

$$J = \frac{\partial(T, s)}{\partial(P, v)} = \begin{vmatrix} (\partial T/\partial P)_v & (\partial T/\partial v)_P \\ (\partial s/\partial P)_v & (\partial s/\partial v)_P \end{vmatrix} = 1. \tag{15}$$

This analytic condition may be regarded in various ways. If the $Pv$ equation of state is known, the condition gives a differential equation which the entropy formula must satisfy. The physical significance of this Jacobian appears if one replaces the partial derivatives in Eq. 15 by suitable physical symbols. Such substitutions are given by the following equations which are easily derived from the definitions of specific heats, of the coefficient of volume expansion $\beta$, and the isothermal bulk modulus $B_T$:[5]

$$(\partial T/\partial P)_v = 1/\beta B_T, \tag{16}$$

$$(\partial T/\partial v)_P = 1/v\beta, \tag{17}$$

$$(\partial s/\partial P)_v = c_v/\beta T B_T, \tag{18}$$

$$(\partial s/\partial v)_P = c_P/v\beta T. \tag{19}$$

[4] For a statement of the relationship between area and Jacobians, see for instance R. Courant, "Differential and Integral Calculus," New York, Nordemann Publishing Co., Inc., 1936, Vol. II, p. 368.

[5] For the most part, the nomenclature and mathematical usage in this article follow Mark W. Zemansky, "Heat and Thermodynamics," New York, McGraw-Hill Book Co., Inc., fourth edition, 1957. The subscript $T$ is added here to avoid confusion later on.

With these interpretations Eq. 15 becomes the familiar thermodynamic identity

$$c_P - c_v = Tv\beta^2 B_T. \tag{20}$$

This identity then is just a way of saying that our transformation is area preserving.

The Jacobian criterion is a symmetric one. Analogous to Eq. 15 we must have also

$$J = \frac{\partial(P, v)}{\partial(T, s)} = 1. \tag{21}$$

This suggests that we should look for an equation dual to Eq. 20. If we use the familiar equation[6]

$$\gamma = c_P/c_v = B_s/B_T, \tag{22}$$

Eq. 20 is easily converted to such a dual form:

$$B_T^{-1} - B_s^{-1} = Tv\beta^2 c_P^{-1}. \tag{23}$$

At this particular point the duality could be expressed more neatly in terms of compressibilities.

From the point of view of this article, the expressions for total differentials of entropy and temperature, namely (using Eqs. 16–19),

$$ds = (c_v/\beta TB_T)dP + (c_P/\beta Tv)dv, \tag{24}$$

and

$$dT = (1/\beta B_T)dP + (1/\beta v)dv, \tag{25}$$

may be regarded as formulas for induced mappings of differentials. Rewriting Eq. 24 as a "*Tds* equation":

$$Tds = (c_v/\beta B_T)dP + (c_P/\beta v)dv, \tag{26}$$

we have a convenient means of deriving the other standard *Tds* equations of thermodynamics. Regarding Eqs. 20 and 26 as linear equations in $c_P$ and $c_v$, we have, by Cramer's rules,

$$c_P\Delta = \begin{vmatrix} Tv\beta^2 B_T & -1 \\ Tds & (\beta B_T)^{-1}dP \end{vmatrix} \tag{27}$$

where

$$\Delta = \begin{vmatrix} 1 & -1 \\ (\beta v)^{-1}dv & (\beta B_T)^{-1}dP \end{vmatrix}. \tag{28}$$

[6] A non-thermodynamic proof of this equation has recently been given by L. G. Hoxton, *Am. J. Phys.*, Vol. 25, p. 460 (1957). The equation will appear also as an incidental conclusion in Section III of this paper.

It is clear from Eq. 25 that

$$\Delta = dT. \tag{29}$$

Hence Eq. 27 may be written

$$c_P dT = Tv\beta dP + Tds. \tag{30}$$

Similarly from

$$c_v \Delta = \begin{vmatrix} 1 & Tv\beta^2 B_T \\ (\beta v)^{-1} dv & Tds \end{vmatrix} \tag{31}$$

one derives the other standard $Tds$ equation:

$$c_v dT = Tds - T\beta B_T dv. \tag{32}$$

It should perhaps be pointed out that by rewriting Eq. 30 and Eq. 32 for the adiabatic case, we can easily derive Eq. 22.

As a final angle of inquiry, one might consider the relation of Eq. 15 to the foundations of thermodynamics. From a moderately sophisticated point of view it is natural to assume as fundamental the fact that the equilibrium states of a simple thermodynamic system can be represented by points in several linear spaces with conjugate coordinates. The restriction that the natural topological mapping of one such space on another is area-preserving is an interesting consequence of the usual laws of thermodynamics. This raises the question (not studied further in this article): could the condition $J = 1$ be conveniently used as one of another set of postulates for thermodynamics? If so, what additional postulates are needed and how can they be framed to fit well in this context? Representing the proposition set forth in Eq. 15 by $J$, and the usual laws of thermodynamics by I, II, III, is there a convenient solution to the equation

$$X + J = \mathrm{I} + \mathrm{II} + \mathrm{III}?$$

### III. BULK MODULUS AND HEAT CAPACITY: MAPPING OF SLOPES

In an ordinary geographic map of a two-dimensional region, the angle between two directions has absolute significance because the same distance scale is used in all directions. In the $Pv$ plane or the $Ts$ plane, directions clearly depend on physical units and arbitrary scales of plotting. The slope of a line in one of these planes has physical dimensions of a fairly complicated sort. This suggests that a more appropriate parameter would be a ratio of slopes. For the $Pv$ plane the slope of the isothermal curve through any given point provides a convenient, ordinarily negative, reference value. This slope, which we denote by $m_T$, is of course equal to a partial derivative with $T$ constant:

$$m_T = (\partial P/\partial v)_T. \tag{33}$$

For any slope $m$ at a given point in the $Pv$ plane we define the slope ratio $\rho$ by

$$\rho = -m/m_T. \tag{34}$$

In terms of $\rho$ isothermal processes are then characterized by the equation $\rho = -1$. Similarly for isobaric and isochoric processes, one has $\rho = 0$ and $\infty$ respectively. For an ideal gas it is interesting to exploit the fact that, for a state $(P_0, v_0)$, one has

$$m_T = -P_0/v_0 = -m_0 \tag{35}$$

where $m_0$ is the slope of the radial line from origin to the state point. In this case it would perhaps be more natural to define $\rho$ by the equation

$$\rho = m/m_0.$$

In the $Ts$ plane a convenient reference slope, ordinarily positive, is the slope $m_v'$ of an isochore, given by the defining equation

$$m_v' = (\partial T/\partial s)_v, \tag{36}$$

or the slope $m_P'$ of an isobar. For any process of slope $m'$ in the $Ts$ plane either the direct ratio $m'/m_P'$ or the inverse ratio $m_v'/m'$ is convenient. The latter choice leads to particularly simple equations; so here we shall use the ratio $\rho'$ defined by

$$\rho' = m_v'/m'. \tag{37}$$

Clearly $\rho'$ has values $\infty$, 1, and 0 for isothermal, isochoric, and adiabatic processes respectively for each equilibrium state of the system.

The physical significance of the quantities $\rho$ and $\rho'$ appears when one recalls the definitions of the isothermal bulk modulus $B_T$ and the specific heat capacity for constant volume $c_v$. It is then clear that the slopes $m_T$ and $m_v'$ may be interpreted in the following way:

$$m_T = -B_T/v, \tag{38}$$

$$m_v' = T/c_v. \tag{39}$$

In general for a process of slope $m$ at the state $(P, v)$ one may define a bulk modulus $B$ by the equation

$$B = -mv. \tag{40}$$

Analogously a general specific heat $c$ may be defined by

$$c = T/m'. \tag{41}$$

The slope ratios $\rho$ and $\rho'$ can now be expressed as ratios of bulk moduli and heat capacities:

$$\rho = -B/B_T, \tag{42}$$

$$\rho' = c/c_v. \tag{43}$$

A process having slope ratio $\rho$ at a point $(P_0, v_0)$ in the $Pv$ plane has correspondingly in the $Ts$ plane a slope ratio $\rho'$ at the point $(T_0, s_0)$ into which the point $(P_0, v_0)$ is mapped. Since $\rho$ and $\rho'$ may have any real values, this transformation may be regarded as assigning to any point on a $\rho$ axis a corresponding point on a $\rho'$ axis. This assignment constitutes a mapping of the $\rho$ axis on the $\rho'$ axis. We shall next seek an equation for this mapping.

To find relations between slopes in the $Pv$ and $Ts$ planes, we may start with the total differential forms

$$dT = (\partial T/\partial P)_v dP + (\partial T/\partial v)_P dv, \tag{44}$$

$$ds = (\partial s/\partial P)_v dP + (\partial s/\partial v)_P dv. \tag{45}$$

Dividing, one obtains

$$m' = \frac{(\partial T/\partial P)_v m + (\partial T/\partial v)_P}{(\partial s/\partial P)_v m + (\partial s/\partial v)_P}. \tag{46}$$

Next it is helpful to express the partial derivatives of the preceding equation in terms of physical quantities. Using definitions and Eqs. 16–19 and 38–41, we obtain the following interpretations:

$$(\partial T/\partial P)_v = -1/v\beta m_T, \tag{47}$$

$$(\partial T/\partial v)_P = 1/v\beta, \tag{48}$$

$$(\partial s/\partial P)_v = -1/v\beta m_v' m_T, \tag{49}$$

$$(\partial s/\partial v)_P = 1/v\beta m_P'. \tag{50}$$

Substituting these expressions in Eq. 46 and simplifying one obtains as an equation for the slope transformation:

$$m' = \frac{m_T - m}{(m_T/m_P') - (m/m_v')}. \tag{51}$$

As an incidental application of this equation, consider its implications for an adiabatic process. In the first place, the slope $m_s'$ is infinite; hence either the numerator of the right member of Eq. 51 is infinite or the denominator vanishes. Barring infinite bulk moduli, one then has the important equation

$$m_T/m_P' = m_s/m_s'. \tag{52}$$

From this equation one can derive the familiar ratio formula for specific heats and bulk moduli (that is, Eq. 22), and one also determines significant special values for $\rho$ and $\rho'$:

$$\gamma = \rho_P' = -\rho_s. \tag{53}$$

Dividing Eq. 51 by $m_s'$ and using Eq. 52, one gets a simple expression for the slope transformation:

$$(m'/m_s') = (m - m_T)/(m - m_s). \tag{54}$$

The inverse transformation may be written

$$(m/m_T) = (\gamma m' - m_s')/(m' - m_s'), \tag{55}$$

or, more symmetrically,

$$(m/m_s) = (m' - m_P')/(m' - m_s'). \tag{56}$$

It is now easy to write down an equation for the transformation of slope ratios. Dividing numerator and denominator of the right member of Eq. 54 by $m_T$, using Eq. 53 together with the definitions of $\rho$ and $\rho'$, and inverting, one obtains:

$$\rho' = (\rho + \gamma)/(\rho + 1). \tag{57}$$

The inverse transformation is

$$\rho = -(\rho' - \gamma)/(\rho' - 1). \tag{58}$$

It is interesting to note that these transformations for slope ratios (as well as those for slopes) are of the form

$$w = (az + b)/(cz + d), \tag{59}$$

with the determinant of coefficients non-vanishing:

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} \neq 0. \tag{60}$$

This means that the mapping of the $\rho$ axis on the $\rho'$ axis is a projective transformation, and hence can be generated by a central projection of one line on another.[7] This is illustrated in Fig. 3. Here for convenience the axes are drawn at right angles with equal scales. Dashed lines, emanating from the center of projection $C$, are labelled with the thermodynamic variable held constant ($v$, $s$, $T$, $P$) for the process in question. Thus, respectively, $\infty$, $-\gamma$, $-1$, 0 map into 1, 0, $\infty$, $\gamma$ for constant $v$, $s$, $T$, $P$. For any less familiar value of $\rho$ the corresponding $\rho'$ is determined similarly by drawing a straight line through $C$ and noting the intersections with both axes. As special cases dotted lines show how

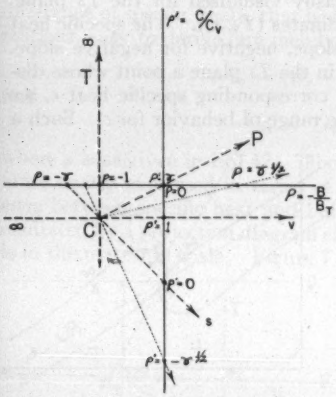


FIG. 3. Projective mapping for ratios of slopes, bulk moduli and specific heats.

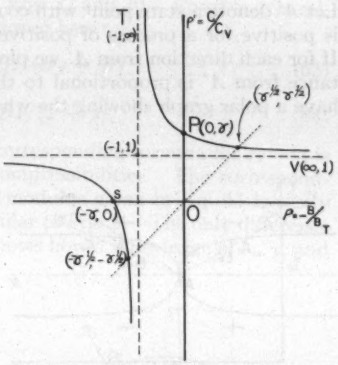


FIG. 4. Conventional graph of mapping for ratios of slopes, bulk moduli, and specific heats.

$\rho = \pm \gamma^{1/2}$ maps onto $\rho' = \pm \gamma^{1/2}$. This last might seem an entirely artificial matter, but a recent note[8] by Kirkpatrick on the geometry of the $Pv$ plane shows that the quantity $\gamma^{1/2}$ has some physical interest.

The relationship between $\rho$ and $\rho'$ can be equally well represented in a conventional graph. Writing Eq. 57 in the form

$$(\rho' - 1)(\rho + 1) = \gamma - 1, \tag{61}$$

one sees that the locus is clearly a rectangular hyberbola with center at the point $(-1, 1)$ in the $\rho\rho'$ plane. This is demonstrated in Fig. 4. The points of particular interest, corresponding to constant $v$, $s$, $T$, $P$,

[7] For a concise sketch of projective transformations, see Garrett Birkhoff and Saunders MacLane, "A Survey of Modern Algebra," New York, The Macmillan Co., 1953, revised edition, pp. 293–298, or John Wesley Young, "Projective Geometry," The Open Court Publishing Co., 1930, Carus Mathematical Monograph No. 4, Section 53.

[8] Paul Kirkpatrick, "Note on the Carnot Cycle," *Am. J. Phys.*, Vol. 25, p. 382 (1957).

are labelled. Infinite values are represented by asymptotes. The "fixed points" of the mapping are indicated by the dotted line $\rho' = \rho$.

The most interesting application of the mapping equation for slopes is to specific heat capacities. In many textbooks on thermodynamics it is pointed out that values of specific heats for a state of a substance vary from $-\infty$ to $+\infty$. But ordinarily no further detail is given about this exhilarating range of values, the discussion being limited to the two values $c_P$ and $c_v$, with perhaps a reference to the adiabatic or isothermal cases. The whole pattern of this variation of specific heats will next be considered. Since specific heat varies inversely as slope in the $Ts$ plane (see Eq. 41), the pattern is easily visualized for the $Ts$ plane. Let $A'$ denote a state point with coordinates $(T_0, s_0)$. The specific heat is positive for a process of positive slope, negative for negative slope. If for each direction from $A'$ we plot in the $Ts$ plane a point whose distance from $A'$ is proportional to the corresponding specific heat $c$, we have a polar graph showing the whole range of behavior for $c$. Such a

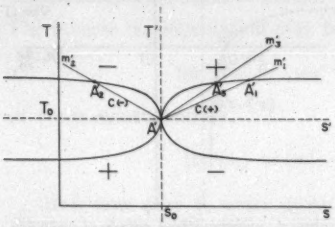


FIG. 5. Polar graph of specific heats in the $Ts$ plane.

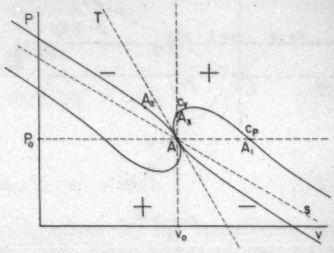


FIG. 6. Polar graph of specific heats in the $Pv$ plane, for exaggerated $\gamma$.

graph is sketched in Fig. 5 where the specific heat in any direction is the distance from $A'$ to the curve. Thus for the sample directions labelled $m_1'$, $m_2'$ the specific heat is represented by the lengths $A'A_1'(+)$, $A'A_2'(-)$. In general, $c$ will be positive for rays having first or third quadrant orientation (relative to $A'$ as origin) and negative for the second or fourth quadrant. The graph shows incidentally that $c$ is infinite for isothermal processes, zero for adiabatic processes. If the process of slope $m_1'$ is isobaric, then $A'A_1'$ has length $c_P$. Similarly $A'A_3'$ has length $c_v$, if $m_3'$ is the isochoric slope at $A'$.

Under the mapping from $\rho'$ to $\rho$ (the inverse mapping given in Eq. 58), the specific heat graph is distorted as shown in Fig. 6 (where the value of $\gamma$ is exaggerated in order to spread out the pattern). But recognizing it as a distortion of Fig. 5 makes it easier to interpret. In Fig. 6 the point $A$ with coordinates $(P_0, v_0)$ is the image of $A'$, and the dashed asymptotes labelled $s$ and $T$ are the images of the axes

labelled $s'$ and $T'$ in Fig. 5. Again the specific heats are proportional to the lengths $AA_1(+)$, $AA_2(-)$, etc.

To get at analytic expressions for specific heats we need merely use Eq. 43 and Eq. 22 to substitute for $\rho'$ and $\gamma$ in the transformation Eq. 57. The result, perhaps surprisingly, is a formula of the type which in analytic geometry is called a ratio formula:

$$c = (c_P + \rho c_v)/(1 + \rho). \tag{62}$$

At this point it may be remarked that Eq. 57 leads to natural generalizations of the two basic thermodynamic equations concerning ratio and difference of specific heats, that is, of Eqs. 22 and 20. Possible generalizations, easy to derive, are merely stated here:

$$c/c_v = (B_s - B)/(B_T - B) \tag{63}$$

and

$$c - c_v = Tv\beta^2 B_T/(1 + \rho), \tag{64}$$

where $\rho$ is as given in Eq. 42. The corresponding formula for $c_P - c$ is more neatly expressed in terms of compressibilities. The correspondence between specific heat and bulk modulus given in Eq. 63 is easily exhibited by a projection diagram similar to Fig. 3. The only difference is in the matter of scale. Figure 7 shows how a knowledge of $c_v$, $\gamma$, and

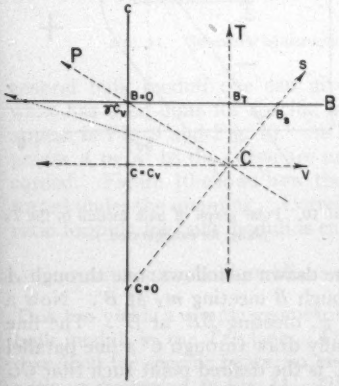


FIG. 7. Projective correspondence between specific heats and bulk moduli.

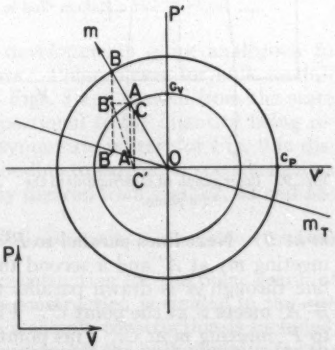


FIG. 8. Geometric construction of specific heats in the $Pv$ plane.

$B_T$ for a given state enables one to locate the projection center $C$ and hence to construct all possible pairings of $B$ and $c$ for that state. For instance the dotted line in this figure shows that for a process to manifest a specific heat halfway between $c_v$ and $c_P$, the effective bulk modulus must be equal to the isothermal bulk modulus—but with opposite sign!

An amusing by-product of Eq. 62 is the possibility of a geometric construction of points on a polar graph like Fig. 6 without any numerical calculations of the parameter $\rho$. All that we need are values for $c_P$ and $c_v$ together with the line tangent to the isothermal curve through the state point of interest in the $Pv$ plane. The construction is as follows. Through the state point, labelled $O$ in Fig. 8, draw a line $v'$ parallel to the $v$ axis, a line $P'$ parallel to the $P$ axis, a line $m_T$ tangent to the isothermal curve through $O$, and a ray $m$ in the direction of the process for which a specific heat is to be plotted. With $O$ as center draw a circle of radius $c_v$ cutting $m$ at $A$ and also a circle of radius $c_P$ cutting

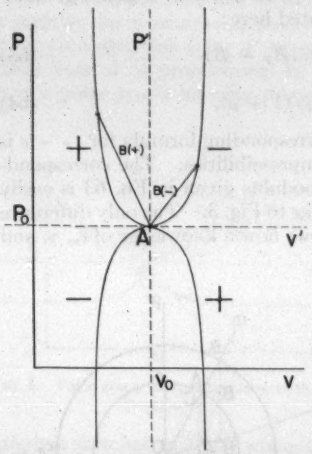


FIG. 9. Polar graph of bulk moduli in the $Pv$ plane.

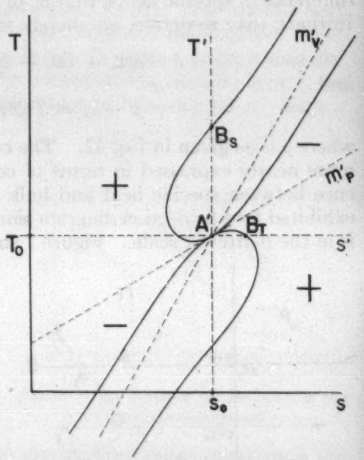


FIG. 10. Polar graph of bulk moduli in the $Ts$ plane, for exaggerated $\gamma$.

$m$ at $B$. Next lines parallel to $P'$ are drawn as follows: one through $A$ meeting $m_T$ at $A'$ and a second through $B$ meeting $m_T$ at $B'$. Now a line through $A$ is drawn parallel to $v'$, meeting $BB'$ at $B''$. The line $B''A'$ meets $v'$ at the point $C'$. Finally draw through $C'$ a line parallel to $P'$ meeting $m$ at $C$. This point $C$ is the desired point such that $OC$ has length equal to the specific heat $c$ on the same scale as the radii $c_v$ and $c_P$. It is somewhat entertaining to carry out this construction for cases where the slope $m$ is close to, but on either side of, the values $m_T$, $\gamma m_T$, 0, $\infty$. It is quite easy to recognize negative values for in such cases the construction line $B''C'$ crosses the line $P'$.

In this discussion of mapping of slope ratios, the concepts of bulk modulus and specific heat capacity play dual roles. Consequently for

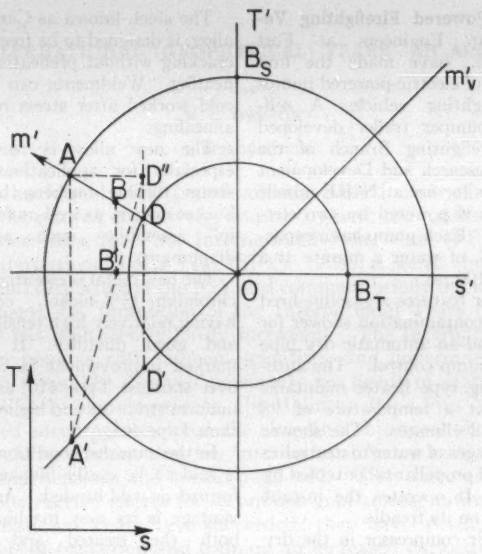


FIG. 11. Geometric construction of bulk moduli in the $Ts$ plane.

general bulk moduli one can give developments quite analogous to what has been done for specific heats. Polar curves for bulk moduli appear in Fig. 9 and Fig. 10. As in Figs. 5 and 6, radii from the state points $A$ or $A'$ to the curve are proportional to the quantity being recorded. Figure 10 shows how the symmetric pattern of Fig. 9 is distorted under the mapping. Corresponding to Eq. 62 for specific heats a ratio formula for bulk moduli is easily derived from Eqs. 22, 42 and 58:

$$B = (B_s - \rho' B_T)/(1 - \rho'). \tag{65}$$

This too yields a simple geometric construction for the polar graph of bulk moduli in the $Ts$ plane. This construction is similar to the one described for specific heats; so only a sample construction is included, without discussion, in Fig. 11. $OB$ represents the bulk modulus for the direction $m'$.

**Electric-Powered Firefighting Vehicle.**—Army Engineers at Fort Belvoir, Va., have made the first application of electric-powered pumps to a firefighting vehicle. A self-operating pumper trailer developed by the Firefighting Branch of the Engineer Research and Development Laboratories for use at NIKE missile installations is powered by two electric pumps. Each pump has a capacity of 50 gal. of water a minute at a pressure of 100 psi.

The trailer features a gasoline-fired heater, a decontamination shower for personnel and an automatic dry pipe system for pump control. The automatic cycling type heater maintains the water at a temperature of 98 degrees in all climates. The shower provides deluges of water to neutralize missile liquid propellants contacted by firefighters. It operates the instant a man steps on its treadle.

A small air compressor in the dry pipe control system maintains a pressure of about 12 psi. on all discharge piping and hose. This air pressure is released when any valve in the system is opened, and starts the pump motors through a pressure switch. The motors automatically stop as soon as all valves are closed. This eliminates the necessity of providing an operator for the trailer.

The trailer also carries a 400-gal. water tank, and a battery and charger for the heater. All components are completely enclosed in an insulated housing.

**Weldable Alloy for Highly Stressed Parts.**—A new air-hardening, weldable and fully martensitic alloy has been developed by The Carpenter Steel Co., Reading, Pa., to meet the need for a metal that can be used for highly stressed parts at temperatures up to 1050 F. where joining is a problem.

The steel, known as Carpenter 404 alloy, is designed to be free from weld cracking without preheating or post-heating. Weldments can be readily cold worked after stress relieving or annealing.

The new alloy is recommended especially for applications such as steam turbine buckets, blades and bucket covers, as well as for "casting in" assemblies such as turbine diaphragms.

The new metal is essentially a 12%-chromium–1½%-nickel composition having relatively high tensile strength and good ductility. It shows a marked improvement in weldability over stainless Type 410, and a more uniform structure and higher hardness than Type 405.

In the annealed condition, the steel is said to be easily blanked, drawn, formed or cold headed. Another advantage is its easy machinability in both the treated and annealed conditions.

Carpenter 404 alloy is made by the company's Mel-Trol process, a new quality control system with patented ingot design. Mel-Trol is used to minimize the causes of inconsistent centerline quality which so often causes erratic service in alloys of this type made by conventional methods.

The alloy offers resistance against a wide range of corrosives, including the atmosphere, fresh water, mine water, steam, carbonic acid, crude oil, gasoline, blood, perspiration, alcohol, ammonia, mercury, soap, sugar solutions and other reagents. It also has good resistance to scaling at elevated temperatures and can be used for continuous service up to about 1200 F.

Forms now available include forging billets; hot rolled bars and forgings, either annealed or heat treated; cold drawn and ground bars; wire and wire rods; and strip, both annealed and tempered.

# THE INTERNATIONAL (GEOPHYSICAL) YEARS—AN APPRAISAL *

BY

N. C. GERSON [1]

## 1. INTRODUCTION

With the formal IGY period already passed, it is of interest to evaluate the returns objectively, and to compare the results with those of its predecessors, the First International Polar Year (FPY) and the Second International Polar Year (SPY). Also, it seems timely to note a paramount deficiency of the IGY and comment briefly upon the future.

In general, the promotion of the International Years (FPY, SPY and IGY) has been tremendously successful. The International Years have been popular with laymen, scientists, and governments. They have been favorably received personally by heads of state. Indeed, during the early planning stages, His Holiness, Pope Pius XII, himself commented encouragingly upon the aims and objectives of the IGY.

It should be obvious that the International Years have ameliorated international tensions and spread good will. They have attempted to inspire constructive efforts for a common goal among nations. In this the International Years have succeeded; they have awakened in men of all levels of education and training an increased curiosity about the planet Earth.

## 2. RESULTS OF THE POLAR YEARS

Even according to the standards of 75 years ago, the results of the FPY of 1882–83 were valuable although not fundamental. FPY data allowed verification of a chart by H. Fritz (6)[2] (1874) indicating the distribution of aurorae over the northern hemisphere. The influence of the arctic and sub-arctic over middle latitude weather was confirmed, and the necessity for adequate reporting networks from this region realized. Also, the FPY provided information for compiling more accurate global magnetic maps, particularly for the arctic, and for evaluating dipole and quadrupole moments of the Earth's field.

Many narratives of the expeditions, a good number of scientific accounts and some analyses of the data were prepared. In later years some comparisons were made utilizing FPY material. However, the tangible products of the years of planning and hardship for the FPY were mainly a series of volumes containing data.

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* A full treatment may be found in "From Polar Years to IGY" in "Advances in Geophysics," Vol. 5, New York, Academic Press, 1959.

[1] Former Secretary, U. S. National Committee for the IGY; now, Consultant, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Mass.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

These data encompassed many fields: aurora, Earth currents, geology, geomagnetism, glaciology, latitude and longitude, meteorology and oceanography. Extensive biological surveys were undertaken on the fauna and flora of the regions concerned. Reports were issued on birds, crabs, crustaceans, echinoderms, fishes, fungi, insects, lichens, mammals, marine invertebrates, mollusks and tunicates. In addition, studies of the ethnology of eskimoes, of a petrified forest at Ft. Conger, and of the preservation of mammoths at Sagastyr were instituted.

Results from the SPY were significantly weightier. They revealed the more critical and more scientific attitude that had been created over the intervening years. While many interests still desired data for future archives, others noted the necessity of describing the mechanisms of atmospheric phenomena.

Probably the outstanding accomplishments of the SPY were:

1. Preparation of northern hemisphere weather maps for most days of the Polar Year.
2. Confirmation of the marked effect of some magnetic storms on ionospheric radio wave reflections.
3. Transit, within one season, of the northeast passage from the Atlantic to the Pacific Oceans (July 28 to October 1, 1933) by the icebreaker, *Siberiakov*.

Magnetic data were reduced at a number of new stations and reports prepared on the degree of magnetic activity. Meteorological data were printed for many additional stations. Calculations of the three-hourly magnetic K indices were completed.

The SPY magnetic observations exemplified but one field wherein the value of the data extended far beyond the International Year: the material still is utilized for investigations of auroral current systems. From SPY observations, correlations were undertaken between auroral and telluric currents, and between magnetic storms and ionospheric disturbances. The data also inspired several reexaminations of FPY material (Bastamov (1), 1929; Henry (7), 1928; Krakau (8), 1925; Rolf and Olsen (11), 1937; Tollner (12), 1932). In all, research papers were published in the disciplines of aurora, cosmic rays, geomagnetism (Earth currents), glaciology, ionospheric physics, meteorology (aerology, atmospheric electricity, nacreous clouds, noctilucent clouds, ozone, radiation), oceanography and astronomy. Investigations were also completed in biology. While this compilation seems impressive, it must be balanced against the miles of recordings, thousands of photographs and millions of readings which were obtained. Considering all factors, it becomes painfully apparent that the analytical return from the SPY was by no means commensurate with the observational input.

It hardly need be pointed out that the SPY differed appreciably

from the FPY. Superficially it seemed to be a repetition of the FPY but on a broader scale. Its magnitude was greater, but more important, the objectives were much more scientific. It had occurred at a sufficient time interval after its predecessor for definite advances to have been made in various geophysical disciplines. Further, new sciences (for example, cosmic rays, ionospheric physics, and auroral physics as distinct from the descriptive aspects of the aurora) had evolved. This general advance in knowledge sharpened curiosity and demanded the keener discernment that entered into the planning. Although its stated objectives were "to observe . . .," there was implicit in the entire venture a hope for deep, continued and critical analyses of a great portion of the data.

### 3. THE IGY

The difference between the IGY and the SPY (as compared to the SPY–FPY) is startling in some respects but less striking in others. For example, the physical entirety of the IGY is almost majestic. An impressive number of nations participated; a legion of scientists was involved and a host of stations cooperated. The total costs are astronomical—easily two billion dollars—but the number of cooperating nations is only 30 per cent greater than those which adhered to the SPY. The increased number of stations and scientists accounts for probably one quarter the cost and merely evolves from a greater effort in most disciplines.

Some objectives in meteorology, magnetism, auroral physics and oceanography are unchanged from those of the SPY if not from the FPY. Other goals stem from advances in the different disciplines.

Probably the truly remarkable feature of the IGY is its boldness of execution in the space-age era. By his suggestion for the inclusion of satellite launchings and the large international invasion of Antarctica, L. V. Berkner correctly assessed the technological capabilities of the times (and probably accounted for three quarters of the funds required). Undoubtedly the space age would have been launched by 1960–65 in any event, and Antarctica sporadically investigated by nations either singly or in consort for many years to come. However, the inclusion within the IGY framework of Earth satellites and Antarctic studies hastened their responsible fruition.

In short, the IGY implemented Karl Weyprecht's original suggestion (whose execution was impossible with the technology of the FPY), by establishing coordinated station networks in the Arctic, Antarctic, and in middle latitudes. It retained major emphasis on geophysical data collections, and especially on those aspects requiring synoptic observations. It continued minor emphasis in biology, topography and geographic exploration. However, the IGY also expanded Weyprecht's original concepts by including longitudinal sectors, emphasizing equatorial regions and embracing interplanetary space.

#### 4. DEFICIENCIES OF THE INTERNATIONAL YEARS

In retrospect the International Years have stimulated activity in the geophysical sciences and contributed somewhat to their general advance. Unfortunately, however, the FPY and the SPY accepted as a measure of accomplishment the standards of the production factory: number of men employed, number of stations operating, monetary cost of station expansion, and number of units (hourly observations) produced. Such standards may be appropriate for a manufactory but they hardly apply to research. Advancement in science can scarcely be measured in terms of the data amassed (witness meteorology, terrestrial magnetism, ionospheric physics). Whether the IGY also will adopt the assembly line measure of success remains to be seen, but some disturbing trends are evident.

In retrospect, it is quite clear that past International Years have produced no great break-through for geophysics. Most of the effort was channelled into data obtainment. The observational program has been tremendously successful, but the sustained research necessary for capitalizing on the accumulated data has been noticeably lacking.

While the International Years have provided reservoirs of potentially useful data, these sources have been mainly untapped. Many succeeding researchers have preferred to utilize their own data, gathered in furtherance of their own theories, surveys or experiments. Other reasons also contribute to the utilization of but a fraction of the International Year data: general reluctance to examine "cold" data obtained by unknown (and often indifferent) observers having different personal bias; lack of a station reliability factor summarizing the over-all equipment condition, operator awareness and general station efficiency; and obtainment of some data without a full appreciation of all factors required on how the material should be analyzed. As an example, we may note how Birkeland's curiosity and interest in aurorae had been stimulated by FPY observations. To investigate his theories more thoroughly, however, he later found it necessary to undertake additional expeditions to Bossekop (Birkeland (2, 3, 4), 1901, 1908, 1909).

The SPY gave to the International Years the global concept envisioned by Weyprecht. The SPY also injected a more scientific attitude into the International Years. But it accepted fully from the FPY—and passed to the IGY—a good measure of the principle of observation for observation's sake. In this connection, the history of major contributions in physics and geophysics indicates a procedure for maximizing the return from an experimental program. Careful delineation and planning of the experiments to be performed, accompanied by effective and meticulous sifting of the data are necessary. The International Years generally have revolved about collections of data for time-averaging or climatological purposes. In one sense this attitude

is understandable in view of the strong role of the collection agencies (ionospheric, auroral, magnetic, meteorological) within the International Year framework. However, to maximize the scientific return on the tremendous IGY investment, positive action must be made to encourage imaginative analyses of the data, preferably at universities and research institutions.

The weaknesses and deficiencies of the analytical programs of the Polar Years were well recognized by past organizers. In his address to the General Assembly of the International Council of Scientific Unions, D. LaCour, president of the Polar Year Commission, stated (9) (1935): "The Second Polar Year is designed to supply information for immediate application to problems now awaiting solution; it is not designed simply to contribute to the existing, overwhelming large mass of undigested observational data from ordinary latitudes." Even earlier, the Polar Year Commission recognized "(the) successful completion (of the investigations) can alone justify all the time, energy and expense which has been devoted to the Polar Year." Yet, within a few years after the SPY, and with but a tiny portion of SPY data analyzed, the opposite view again appeared. Debenham (5) (1935) wrote, "The conclusions which have been drawn from these (the First and Second International Polar Year) results are, as yet, scarcely in full circulation, but few meteorologists do not sigh for more and more data from the polar regions." (It may be asked, seriously: Will meteorologists with mountains of undigested IGY data molding in warehouses utter the same sighs several years hence?) Fifteen years after conclusion of the SPY, Laursen (10) (1948) reported, "In terrestrial magnetism, the bibliography will reveal, similarly as in meteorology, the need for completion of various national programs."

The preceding statements forcefully demonstrate that the previous International Years, consciously or unconsciously, concentrated on garnering hordes of records. The IGY of 1957–58 is collecting literally billions of observations, and hundreds of thousands of kilometers of ink and photographic recordings. (The problem is further compounded by many millions of observations taken and stored within the past decade; many unreduced, and most unanalyzed.)

The availability of these records has some utility. But by no means does the value of availability compare with the value of research results —the new concepts, ideas or relationships which careful examination and thought provide. In geophysics, a shift in emphasis from data gathering to data analyses seems long overdue. Also, in view of the immediate practical problem of merely storing the large physical volume of the records, the entire synoptic observational mechanism should be re-evaluated. Concern must be given to the problem of selecting representative stations and representative networks typical of regions or

anomalies rather than the unrestricted willy-nilly establishment of observing stations. Like tactile nerve endings on the skin, which have different densities in different areas, geophysical sensors need not be equally spaced over the globe.

It should be feasible in today's technology to design minimal, adequate and maximal station networks for a given discipline within definite geographic areas.

On a long range basis, the answer undoubtedly lies in the implementation of automatic sensor-computer devices which link adequate observing networks and a central computer-memory apparatus. Recordings, either continuous or at predetermined time intervals, feed the memory of the system. The computer, in addition to furnishing rapid integrating and analyzing functions, as programmed, would also provide simple time-averages which considered the last observation. Other sections of the computer would be programmed to test new theories on global patterns and global circulation systems, and one section would be reserved solely for the prognostication services. Thus, the sensor-computer systems could indicate present and past states, and forecasted future conditions on mass movements in the atmosphere, hydrosphere, or ionosphere; state of the weather, ionosphere, water supply, floods or droughts; solutions of the wave equation in seismology, oceanography, meteorology or ionospheric physics, etc.

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### 5. ANALYTICAL VALUE OF THE INTERNATIONAL YEARS

By their very nature, the International Years were concerned with data obtainment. Major analyses consequently were deferred or concluded after termination of the enterprise. Nevertheless, in retrospect, the geophysical advances occurring directly as a result of the International Years have been modest. The greatest progress in planetary physics occurred in the quieter, more academic atmosphere found between the International Years.

It would be unwise to conclude an analysis of the value of the International Years without mention of some of its inherent deficiencies. First, the pressures and propaganda to "man the garrisons," for the International Year stations siphon a certain percentage of competent theoreticians into administration, logistics and geophysical gadgetry. Secondly, the promotional activities attract a certain number of geophysical mercenaries, whose interest, enthusiasm and objectivity are open to question.

It should be evident that the mere collection of data does not guarantee scientific advancement. Indeed, a conspicuous example to the contrary is found in meteorology, where the dearth of reports from foreign countries during World War I spurred development of the methods of Polar Front Analysis by Norway.

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**Acoustic Noise Generator Tests Rocket Components.**—A new electromechanical loudspeaker producing up to 166 decibels of random noise has been developed by Avco Research and Advanced Development Division, Wilmington, Mass., for acoustic noise testing of missile and rocket components and systems to military specifications. At single or discrete frequencies, up to 170 decibels can be generated. "Components and systems that pass mechanical vibration tests can still fail in the high acoustic noise levels produced by a rocket or jet engine," the Avco scientists stated.

Since it is impractical and expensive to operate rocket engines in the laboratory, the Avco Acoustic Noise Generator has been developed to simulate rocket engines' noise which is random in amplitude.

Even components that are shock-mounted or isolated from mechanical vibration may fail under the stress of acoustic noise during launch, powered flight or re-entry of a missile. Mechanical vibration must be passed to the component through the shock mounts which cut down high-frequency vibration. But acoustic vibration is passed directly to the component through the surrounding air, exciting resonances in the component even at frequencies above the natural frequency of the shock mounts.

The loudspeaker designed by Avco is an electromagnetic unit with a 12-inch-diameter moving coil. The new acoustic noise generator was designed to be compatible with the electronic power supplies and control consoles now being used with vibration test equipment. Heart of the unit is the plastic and Fiberglass reinforced moving coil diaphragm assembly which is suspended by U-shaped beryllium-copper springs from the electromagnetic housing. The acoustic energy produced by the diaphragm is focused and sent through an expanding horn to a four-inch-diameter opening in the speaker structure.

In actual test the acoustic noise generator is used with a progressive wave tube or reverberant chamber. With a progressive wave tube the sound wave or acoustic noise generated is sent down the tube and absorbed at the end. The component or small system under test is placed in the tube between the generator and the absorbing material. Testing the component at different angles in the tube will quickly show mechanical fatigue and failure of the component.

For larger components or systems a reverberant chamber is used, and the material is placed in the chamber through a small door. In a reverberant chamber the noise produced reverberates and reflects from the surfaces of the enclosure around the subject under test.

The Avco acoustic noise generator is 35 in. high, 24 in. long and 26 in. wide. It has a random noise sound intensity of 163 decibels, plus or minus 3 decibels, and at discrete frequencies produces sound intensities up to 170 decibels. The random noise input power is 3 kilowatts. The frequency range is 20 to 2400 cps. with a nominal impedance of two ohms.

V.26
1959

# PREDICTING ABSORPTION SPECTRA FOR COMPOSITE SOLUTIONS

BY

VICTOR W. BOLIE[1]

## I. INTRODUCTION

The determination of the composition of chemical substances by the use of spectral transmission measurements is recognized as one of the most important techniques of analysis. Simultaneous measurement of absorptions at several different wavelengths, followed by appropriate solution of the corresponding simultaneous equations, has been found to be a valuable aid for control of chemical processing plants. In order to gain a better insight to the spectral transmission properties of composite solutions, it is worthwhile to consider the problem of predicting the spectral response of a solution of spectrally different chemicals. The purpose of this paper is to develop from Beer's Law an equation for the spectral response of a composite solution, and to compare the results calculated according to the theory with the results measured by a colorimeter.

## II. SPECTRAL RESPONSE THEORY

According to Beer's Law, the per cent transmittance $P(\lambda)$ of a semi-transparent solution containing an absorbing substance whose concentration is $c$, when illuminated by radiation of wavelength $\lambda$, is given by the formula

$$\frac{P(\lambda)}{100} = 10^{-ck(\lambda)}$$

where $k(\lambda)$ is a transmission coefficient (whose dimensions cancel those of concentration) which depends on the radiation wavelength and the thickness of the sample. This equation may also be written as

$$\log \frac{100}{P(\lambda)} = ck(\lambda),$$

which may be called the logarithmic form of Beer's Law.

A system of $n$ solutions of different chemicals in the same type of solvent has spectral responses which can be represented by the set of equations

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$$\frac{P_1(\lambda)}{100} = 10^{-c_1 k_1(\lambda)}$$

$$\frac{P_2(\lambda)}{100} = 10^{-c_2 k_2(\lambda)}$$

$$\cdots = \cdots$$

$$\frac{P_n(\lambda)}{100} = 10^{-c_n k_n(\lambda)}$$

in which $P_i$, $c_i$, and $k_i(\lambda)$ represent, respectively, the per cent transmittance, the concentration, and the transmission coefficient of the $i$th solution. On account of the logarithmic behavior of radiation absorption, the per cent transmittance $P(\lambda)$ for a composite solution of the $n$ different chemicals represented in these equations can be expressed as

$$\log \frac{100}{P(\lambda)} = \sum_{i=1}^{n} c_i k_i(\lambda).$$

Substituting the individual equations into this expression gives

$$\log \frac{100}{P(\lambda)} = \sum_{i=1}^{n} \log \frac{100}{P_i(\lambda)},$$

which may be written in the equivalent form,

$$\log \frac{100}{P(\lambda)} = \log \prod_{i=1}^{n} \frac{100}{P_i(\lambda)},$$

since the sum of the logarithms of $n$ factors is identical to the logarithm of the product of the $n$ factors. Taking the antilog of both sides of this equation gives

$$\frac{P(\lambda)}{100} = \prod_{i=1}^{n} \frac{P_i(\lambda)}{100},$$

as the theoretical equation for the per cent transmittance of the composite solution.

The last result shows how the per cent transmittance of a composite solution of spectrally different chemicals having various concentrations in the solution can be calculated for any wavelength if the transmittance curves for the individual substances are known for the same concentrations. If the concentrations of the various substances in the composite solution are different from those for which the individual transmittance curves are known, the above equation may be modified to account for the concentration differences. From the formula

$$\frac{P_i(\lambda)}{100} = 10^{-c_i k_i(\lambda)},$$

for the per cent transmittance of a solution of a single absorbing substance having a concentration $c$, it is apparent that the per cent transmittance for the same substance at another concentration $c'$ is given by

$$\frac{P_i'(\lambda)}{100} = 10^{-c_i' k_i(\lambda)}.$$

Combining these two equations gives

$$\frac{P_i'(\lambda)}{100} = \left[\frac{P_i(\lambda)}{100}\right]^{c_i'/c_i},$$

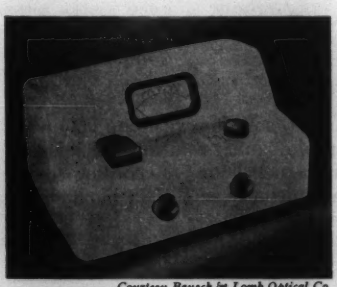
and making use of this result in the equation for the composite solution gives

$$P'(\lambda) = 100 \prod_{i=1}^{n} \left[\frac{P_i(\lambda)}{100}\right]^{c'/c},$$

as the formula for the prediction of the spectral transmission for the composite solution.

### III. EXPERIMENTAL CONFIRMATION

In order to compare the theoretical results predicted by the formula developed in the preceding section with those obtained by experiment, some colorimetric measurements were performed using binary solutions. The measuring instrument used for the experiment was the Bausch and Lomb "Spectronic 20" Colorimeter shown in Fig. 1. The spectral response of the phototube in the instrument is illustrated in Fig. 2.



*Courtesy Bausch & Lomb Optical Co.*

FIG. 1. Bausch and Lomb "Spectronic 20" Colorimeter.

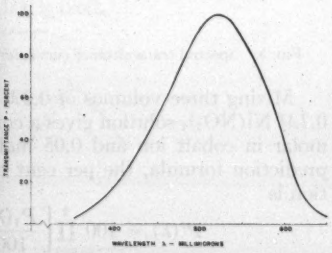



FIG. 2. Spectral response of GE 5581 phototube measured with water in B and L "Spectronic 20" colorimeter.

The spectral transmittance curves obtained for $0.2M$ aqueous solutions of $CoSO_4$ and $Ni(NO_3)_2$ are shown in Fig. 3. The greenish color of the nickel ion is clearly evident. The tendency of the curve is to maximize in the neighborhood of 500 millimicrons.

When a given volume of a 0.2$M$ solution of $Ni(NO_3)_2$ is mixed with an equal volume of a 0.2$M$ solution of $CoSO_4$ the resultant solution is 0.1 molar in each metallic ion. According to the prediction formula, the per cent transmittance for the composite binary solution is

$$P'(\lambda) = 100 \prod_{i=1}^{2} \left[\frac{P_i(\lambda)}{100}\right]^{0.1/0.2}$$

$$= 100 \left[\frac{P_1(\lambda)}{100}\right]^{1/2} \left[\frac{P_2(\lambda)}{100}\right]^{1/2}$$

$$= \sqrt{P_1(\lambda) P_2(\lambda)}.$$

Thus, for the case in which equal volumes of two equimolar solutions are mixed together, the transmittance curve for the composite binary solution is the geometric mean of the transmittance curves for the individual solutions. The theoretical curve thus obtained is shown in Fig. 4, together with the results of the corresponding colorimetric measurements.

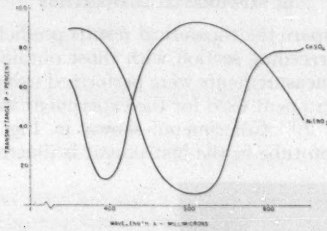


FIG. 3. Spectral transmittance curves for 0.2 molar solutions of $CoSO_4$ and $Ni(NO_3)_2$.

Mixing three volumes of 0.2$M$ $CoSO_4$ solution with one volume of 0.2$M$ $Ni(NO_3)_2$ solution gives a composite binary solution which is 0.15 molar in cobalt ion and 0.05 molar in nickel ion. According to the prediction formula, the per cent transmittance of such a binary solution is

$$P'(\lambda) = 100 \prod_{i=1}^{2} \left[\frac{P_1(\lambda)}{100}\right]^{0.15/0.20} \left[\frac{P_2(\lambda)}{100}\right]^{0.05/0.20}$$

$$= 100 \left[\frac{P_1(\lambda)}{100}\right]^{3/4} \left[\frac{P_2(\lambda)}{100}\right]^{1/4}$$

$$= \sqrt[4]{[P_1(\lambda)]^3 [P_2(\lambda)]}.$$

The expected stronger dependence of the transmittance curve on the transmission behavior of the cobalt ion is evident in this equation.

Numerical results calculated from this formula are plotted in Fig. 5, together with the results of the corresponding colorimetric measurements.

Mixing one volume of $0.2M$ $CoSO_4$ solution with three volumes of $0.2M$ $Ni(NO_3)_2$ gives a binary solution which is 0.05 molar in cobalt ion and 0.15 molar in nickel ion. According to the prediction formula, the per cent transmittance of such a binary solution is

$$P'(\lambda) = 100 \prod_{i=1}^{2} \left[\frac{P_i(\lambda)}{100}\right]^{0.05/0.20} \left[\frac{P_2(\lambda)}{100}\right]^{0.15/0.20}$$

$$= 100 \left[\frac{P_1(\lambda)}{100}\right]^{1/4} \left[\frac{P_2(\lambda)}{100}\right]^{3/4}$$

$$= \sqrt[4]{P_1(\lambda)[P_2(\lambda)]^3}.$$

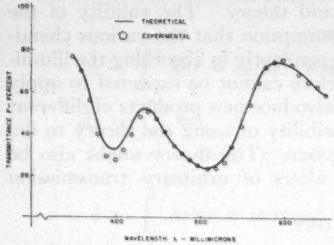



FIG. 4. Spectral transmittance curves for aqueous solution $0.10M$ in $Ni(NO_3)_2$ and $0.10M$ in $CoSO_4$.

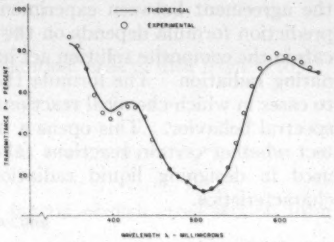



FIG. 5. Spectral transmittance curves for aqueous solution $0.05M$ in $Ni(NO_3)_2$ and $0.15M$ in $CoSO_4$.

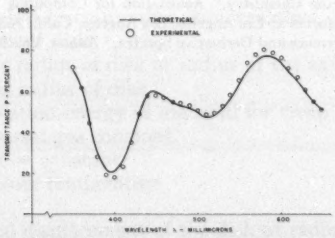



FIG. 6. Spectral transmittance curves for aqueous solution $0.15M$ in $Ni(NO_3)_2$ and $0.05M$ in $CoSO_4$.

The expected stronger dependence of the transmittance curve on the transmission behavior of the nickel ion is evident in this equation. The numerical results computed from this formula are plotted in Fig. 6, together with the results of the corresponding colorimetric measurements.

From Figs. 4, 5, and 6 it is seen that the agreement between the theoretical prediction and the experimental results is generally good. All three graphs show some discrepancy between experiment and theory when the illumination wavelength is in the neighborhood of 400 millimicrons. However, inspection of Fig. 1 shows that the phototube response for this wavelength is weak, in which case the response of the phototube is not likely to be a completely linear function of illumination intensity. Better agreement between experiment and theory would be expected with more elaborate equipment involving gain-stabilized amplifiers and detectors of broader response.

## IV. CONCLUSIONS

The preceding discussion outlines the development of a formula for predicting the spectral transmission for a composite solution, and shows the agreement between experiment and theory. The validity of the prediction formula depends on the assumption that the various chemicals in the composite solution act independently in absorbing the illuminating radiation. The formula therefore cannot be expected to apply to cases in which chemical reactions introduce new products of different spectral behavior. This opens a possibility of using the theory to detect whether certain reactions take place. The theory might also be used in designing liquid radiation filters of arbitrary transmission characteristics.

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# A CREEP ANALYSIS OF ROTATING SOLID DISKS

BY

B. M. MA [1]

ABSTRACT

Based on the maximum shear theory, an analysis of creep deformations and stress distributions in rotating solid disks operating at elevated temperature is presented. At steady-state condition, creep rate is assumed to be the product of a function of stress, a function of time and a function of temperature. It is further assumed that with metallic material available for gas turbine disks, the creep laws follow (*a*) power function stress-creep-rate relation for relatively low stresses and (*b*) exponential function stress-creep-rate for relatively high stresses. The case of variable-thickness and uniform-temperature disk is analyzed and discussed.

NOTATIONS

$A = \int_{r_i}^{r} h dr$ = radial cross-sectional area of disk from $r_i$ to $r$

$A_0 = \int_{r_i}^{r_o} h dr$

$h = cr^m$ = disk thickness, ($h_i = cr_i^m$, $h_0 = cr_o^m$), and $c$, $m$ = constants

$I = \int_{r_i}^{r} hr^2 dr$ = moment of inertia of disk cross section from $r_i$ to $r$

$I_0 = \int_{r_i}^{r_o} hr^2 hr$

$k, K$ = constants

$n$ = material creep number, dimensionless

$r$ = radius of disk

$r_i$ = inner radius of disk or radius of the axis of disk

$r_o$ = outer radius of disk

$H$ = activation energy of material for creep

$R$ = universal gas constant

$a = H/R$ = constant

$T$ = absolute temperature

$t$ = time

$u$ = radial displacement of the disk at radius $r$

$\dot{u}$ = rate of radial displacement at radius $r$

$\dot{u}_i$ = rate of radial displacement at $r_i$

$x = r/r_o$, ($x_i = r_i/r_o$)

$y = \sigma_r/\sigma_t$ = ratio of radial stress to tangential stress

$\sigma$ = equivalent or effective stress

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$\sigma_e$ = $\rho\omega^2 r_o^2$ = equivalently inertial stress in rotating thin ring of radius $r_o$
$\sigma_0$ = material creep modulus, having dimensions of stress
$\sigma_1, \sigma_2, \sigma_3$ = principal stresses along axes 1, 2, and 3, respectively
$\sigma_t, \sigma_r, \sigma_z$ = tangential, radial and axial stresses of the disk
$\sigma_{tav} = \int_{r_i}^{r_o} h\sigma_t dr / A_0$ = average tangential stress
$\sigma_{t_i}, \sigma_{r_i}, \sigma_{r_o}$ = tangential and radial stresses at $r_i$ and $r_o$, respectively
$\dot{\epsilon}$ = creep rate or effective creep rate
$\dot{\epsilon}_1, \dot{\epsilon}_2, \dot{\epsilon}_3$ = principal creep rates along axes 1, 2, and 3, respectively
$\dot{\epsilon}_t, \dot{\epsilon}_r, \dot{\epsilon}_z$ = tangential, radial, and axial creep rates of the disk
$\dot{\epsilon}_{t_i}, \epsilon_{t_i}$ = tangential creep rate and creep strain at $r_i$
$\epsilon_1, \epsilon_2, \epsilon_3$ = principal creep strains along axes 1, 2, and 3, respectively
$\epsilon_t, \epsilon_r, \epsilon_z$ = tangential, radial and axial creep strains of the disk
$\rho$ = density of the disk, or $\rho = \frac{\gamma}{g}$ where $\gamma$ = specific weight and
$g$ = gravitational acceleration
$\omega$ = angular speed of the disk.

## 1. INTRODUCTION

In the design of gas turbines for jet propulsion, the creep deformations and stress distributions in the turbine disk operating at high temperature are of much practical importance. As the speed of gas turbines is greatly increased, the stresses in rotating disk due to centrifugal forces and thermal gradients usually exceed the yield strength of ductile material and result in creep and plastic flow.

In many practical cases, creep deformations are generally confined to the primary stage of creep, in which the creep rate gradually diminishes and approaches to a steady state as creep progresses. Recently, however, efficient design of turbine disks at high temperature frequently requires that advantage could be taken of the secondary stage of creep, where the creep rate is steady or minimum, and, in some cases, of the tertiary stage of creep provided that the assured creep strain and ductility of the material be allowable.

By presence of a central hole in rotating disk, the yield and bursting speeds of it are materially reduced, which is generally in proportion to the section area of material removed (1).[2] Therefore, in many practical applications of high speed turbines, solid disks without bore are used when the disk is made integral with a shaft.

Based on the distortion energy theory, that is, either the stress-creep-rate relation follows the St. Venant-Von Mises type or the yield condition follows the Von Mises criterion (or Von Mises-Hencky criterion), the creep analyses for rotating disks have been developed and discussed by Bailey (2), Odquist (3), Soderberg (4), Popov (5), Millen-

[2] The boldface numbers in parentheses refer to the references appended to this paper.

son and Manson (6), Johnson (7) and Wahl and his associates (8). To solve the stress and strain equations derived from the distortion energy theory, either by the numerical integration method or by the finite difference method, has been very tedious. For simplicity, creep analysis in rotating hollow disks based on the Tresca criterion and its associated flow rule has been introduced by Wahl (9). In that paper, he neglected radial creep rate of the disk and thereby the stress equations were obtained in closed form by direct integrations. In a most recent paper by Wahl (10), he removed the restriction $\sigma_r < \sigma_t$, and extended it to $\sigma_r = \sigma_t$ covering the additional cases of constant thickness solid disk and rotor, so that some radial creep rate may be taken into account.

This paper based on the maximum shear theory presents the two creep laws, namely, power function and exponential function stress-creep-rate relations, for the different ranges of stress (instead of this, some authors insist on the power-function creep law, while others maintain the hyperbolic sine creep law) for rotating solid disks. The stress and strain equations derived from the maximum shear theory are simpler than that from the distortion energy theory. While on the other hand, a comparatively reasonable approach for disk design is considered, without sacrificing the radial creep rate of disks for simplicity. We realize that an efficient disk design is one of the important and complicated problems in practical applications.

## 2. BASIC ASSUMPTIONS

In the analysis for long-time creep of rotating solid disks at high temperature and at steady-state condition, the following basic assumptions are made:

(*a*) The material is isotropic.
(*b*) The density of the material remains constant.
(*c*) The yield condition follows the Tresca criterion.
(*d*) The axial stress may be neglected and the tangential and radial stresses are uniform across the thickness of the disk.

From assumption (*a*) it is understood that the principal axes of the strain rate must coincide with those of the principal stresses if the material is isotropic. At the same time, the principal rates of shear strain must be proportional to the corresponding principal shear stresses.

Assumption (*b*) implies that the change of volume of the material is zero during creep and plastic flow, that is, the equation of incompressibility is applicable.

In assumption (*c*), the well-known Tresca criterion, that is, the maximum shear theory, was formulated from the experimental results of lead extrusion through orifices and has been widely used in machine design.

From assumption (*d*), the plane-stress problem of the rotating disk is established as usual, that is, the axial stress vanishes. It also implies that the disk is thin enough compared to its outside diameter and the temperatures are uniform across the thickness of the disk. Furthermore, the steady-state condition is defined as that in which the stresses in the disk do not vary with time.

It is realized that in the present design practice, both the distortion energy theory and the maximum shear theory are common to use. Now, in choosing the latter for the creep analysis of rotating disks at high temperature, the following advantages may be summarized:

1. The use of the maximum shear theory frequently leads to a simpler system of stress and strain equations in a creep and plastic solid than the use of the distortion energy theory. This is particularly true for creep analysis in rotating disks. The work to obtain the stress distributions and creep deformations in the disk will be appreciably reduced when the simple stress equations, derived from the maximum shear theory, for successive approximations are performed.
2. The creep deformations obtained from the maximum shear theory are usually larger and in better agreement with the average test data of rotating disks than that predicted by the distortion energy theory (**8**). Experience shows that the cause of failure in heat-resisting alloys is frequently attributed to excessive creep deformations. With materials for turbine-disk use such as 19–9–DL, Timken 16–25–6 alloy steels the maximum shear theory will generally make the disk design on the safe side.

### 3. GENERAL EQUATIONS FOR CREEP RATES AND DEFORMATIONS

For a perfectly elastic solid at normal or uniform temperature, the stresses and strains are independent of the stress and strain rates, because the time factor does not enter into Hooke's law. However, in a creep and plastic solid such as rotating thermal disk, the behavior is quite different. Due to the interaction of creep and plastic flow, together with the variation of thermal gradients in the disk, the stresses and strains will depend upon strain rates, that is, depend upon time.

In general, the creep rate may be assumed to be equal to the product of a function of stress, $F(\sigma)$, a function of time $f(t)$ and a function of temperature, $g(T)$, that is,

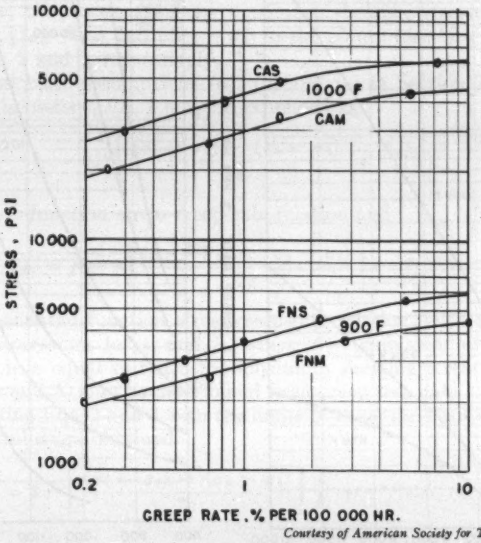
$$\epsilon = F(\sigma)f(t)g(T) \tag{1}$$

on the basis of experimental results.

It is further assumed that the function of stress $F(\sigma)$ may be expressed quantitatively, fitting the creep test data of steels, by

(*a*) the power function $\sigma^n$ for relative low stresses (**2**), (**13**), and
(*b*) the exponential function $e^{\sigma/\sigma_0}$ for relatively high stresses.

To show these, power function stress-creep-rate relations for 0.5 per cent molybdenum steel from long-time creep-test data are plotted in Fig. 1 (11), and hyperbolic sine or exponential function stress-creep-rate relations for 35 per cent nickel 19 per cent chromium steel from long time creep-test data are given in Fig. 2 (12). From the same test data for 35 per cent nickel 19 per cent chromium alloy steel, the temperature-creep-rate-stress relations are plotted in Fig. 3 (12).




*Courtesy of American Society for Testing Materials*

FIG. 1. The power function stress-creep-rate relation of 0.5 per cent Mo steel.

| | |
|---|---|
| F—fine grain | A—annealed |
| C—coarse grain | S—cementite fully spheroidized |
| N—normalized | M—spheroids fully massed |

The above assumptions for creep laws may interpret the facts that some test data of the stress-creep-rate relation can be only represented by the creep law of $\sigma^n$, for the relatively low stresses, Fig. 1, while others can only be represented by the creep law of $e^{\sigma/\sigma_0}$, or $\sinh(\sigma/\sigma_0)$, for the relatively high stresses, Fig. 2. However, there are some exceptional test data of creep at the range of moderate stresses, where creep rates can be approximately expressed by the creep laws of both $\sigma^n$ and $e^{\sigma/\sigma_0}$. It appears evident that in the case of complete-set creep tests run from the relatively low stresses up to the relatively high stresses, the two

creep laws from $\sigma^n$ to $e^{\sigma/\sigma_0}$ must meet at some region of transition. In other words, the region of transition must occur at the moderate stresses where $\sigma^n$ and $e^{\sigma/\sigma_0}$ give the same values for creep rates.

It should be also noted that the hyperbolic sine law for the stress-creep-rate relation has been proposed by Nadai (14). It is obvious that at the high stresses, sinh $(\sigma/\sigma_0)$ will simply reduce to $\frac{1}{2}e^{\sigma/\sigma_0}$.

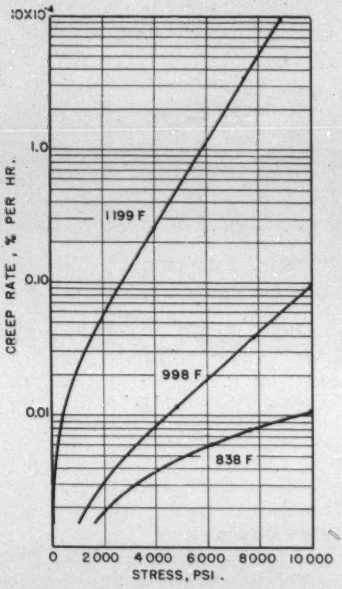



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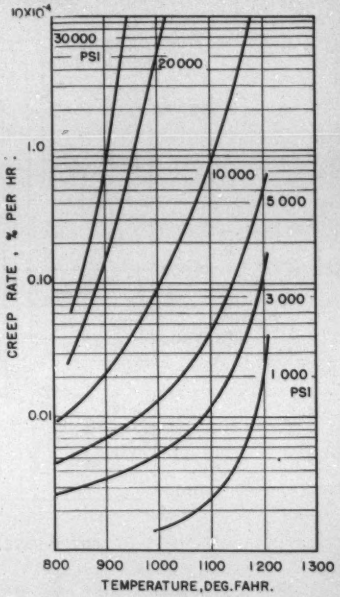
FIG. 2. The exponential function stress-creep-rate relation of 35 per cent Ni and 19 per cent Cr steel.




*Courtesy of American Society for Testing Materials*

FIG. 3. The temperature-creep-rate-stress relations of 35 per cent Ni and 19 per cent Cr steel.

As to the function of temperature $g(T)$, Johnson suggested that the effect of temperature on creep rate may be given by $e^{bT}$, where $b$ is a constant and $T$ the absolute temperature (7). Now, based on the creep test data (15), it is assumed that creep rate is proportional to exponential function of $e^{-H/RT}$ or $e^{-a/H}$ in which $H$ is the activation energy of material for creep as defined in the nomenclature. For a given material $H$ is insensitive to dilute solid solution alloying, grain size, dispersions of stable intermetallic compounds, cold work, stress and

temperature. For pure metals $H$ is constant and is approximately equal to the corresponding activation energies for self-diffusion.

Although there is no actual confirmation of the ineffectiveness of the hydrostatic stress on the creep properties being found experimentally, based on the test data that under internal pressure the lead pipes produce no axial creep, it may be postulated that the creep is due to shear, uninfluenced by the tensile or compressive stress acting on planes where there is shearing stress (2). Now, let the principal stresses be in the order $\sigma_1 > \sigma_2 > \sigma_3$, then the maximum shearing stresses will be $\frac{1}{2}(\sigma_1 - \sigma_3)$, $\frac{1}{2}(\sigma_2 - \sigma_3)$ and $\frac{1}{2}(\sigma_1 - \sigma_3)$ in the planes bisecting the principal axes 1, 2 and 3, respectively.

Based on basic assumptions (*a*), (*b*) and (*c*) in Section 2 and the foregoing discussions, Eq. 1 may be expressed as

$$\dot{\epsilon}_1 = k\sigma^n \left[ \frac{(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1)}{2\sigma} \right] e^{-a/T} f(t) \tag{2}$$

for the power-function stress-creep-rate relation and

$$\dot{\epsilon}_1 = Ke^{\sigma/\sigma_0} \left[ \frac{(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1)}{2\sigma} \right] e^{-a/T} f(t) \tag{3}$$

for the exponential function stress-creep-rate relation, with the corresponding expressions for $\dot{\epsilon}_2$ and $\dot{\epsilon}_3$, where $\sigma$ = equivalent or effective stress, which is equal to twice the maximum shearing stress; and the constants $k$ and $K$ may be determined from creep test data.

Integrating Eqs. 2 and 3 with the limits of time, the basic equations for creep strains are obtained

$$\epsilon_1 = k\sigma^n \left[ \frac{(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1)}{2\sigma} \right] \int_0^t e^{-a/T} f(t)dt, \text{ etc.} \tag{4}$$

and

$$\epsilon_1 = Ke^{\sigma/\sigma_0} \left[ \frac{(\sigma_1 - \sigma_2) - (\sigma_3 - \sigma_1)}{2\sigma} \right] \int_0^t e^{-a/T} f(t)dt, \text{ etc.} \tag{5}$$

Remember that for the steady-state conditions of creep the stresses do not vary with time while the temperature and time are generally not independent of each other.

#### 4. CREEP ANALYSIS FOR SOLID DISKS

Based on the maximum shear theory, the principal stresses in the disk, Fig. 4, may assume the biaxial stress systems as follows:

$$\sigma_t > \sigma_r > \sigma_z = 0 \quad \sigma = \sigma_t; \quad \text{at} \quad \sigma_t \equiv \sigma_1, \quad \sigma_r \equiv \sigma_2, \quad \sigma_z \equiv \sigma_3 \tag{6}$$

$$\sigma_r > \sigma_t > \sigma_z = 0 \quad \sigma = \sigma_r; \quad \text{at} \quad \sigma_r \equiv \sigma_1, \quad \sigma_t \equiv \sigma_2, \quad \sigma_z \equiv \sigma_3. \tag{7}$$

In this paper, we shall limit further discussion to the first system only. Here, it may be worthy to note that for the special case of the plane stress problem of disk, the equivalent or effective stress of the Von Mises criterion and the Tresca criterion will become identical when $\sigma_r = \sigma_t$.

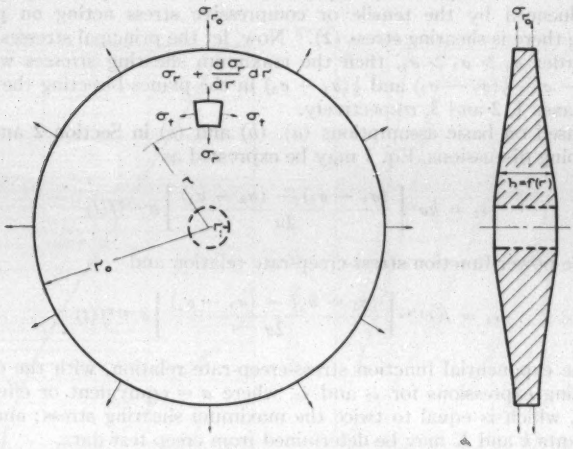



FIG. 4. Elements of a solid disk.

Now, consider the element at radius $r$ of the disk, Fig. 4. The equation of equilibrium is given by

$$d(hr\sigma_r)/dr - h\sigma_t + \rho\omega^2 r^2 h = 0.$$

From basic assumption ($b$) and Eqs. 6, substituting $\sigma_t$ for $\sigma$ in Eqs. 2 and 3 and putting $y = \sigma_r/\sigma_t$, we have

$$\left.\begin{aligned} \dot{\epsilon}_t &= k\sigma_t{}^n(1 - y/2)e^{-a/T}f(t) \\ \dot{\epsilon}_r &= k\sigma_t{}^n(y - \tfrac{1}{2})e^{-a/T}f(t) \\ \epsilon_z &= -(\dot{\epsilon}_t + \dot{\epsilon}_r) \end{aligned}\right\} \tag{8}$$

for the power function stress-creep-rate relation, and

$$\left.\begin{aligned} \dot{\epsilon}_t &= Ke^{\sigma_t/\sigma_0}(1 - y/2)e^{-a/T}f(t) \\ \dot{\epsilon}_r &= Ke^{\sigma_t/\sigma_0}(y - \tfrac{1}{2})e^{-a/T}f(t) \\ \epsilon_z &= -(\epsilon_t + \epsilon_r) \end{aligned}\right\} \tag{9}$$

for the exponential function stress-creep-rate relation. By integrating Eqs. 8 and 9 with the limits of time from 0 to $t$, the components of creep strain can be readily obtained.

### 5. VARIABLE-THICKNESS AND UNIFORM-TEMPERATURE DISK—STEADY-STATE CONDITION

#### (a) *Power Function Stress-Creep-Rate Relation*

From Eqs. 8 the following functions can be defined (see Appendix I).

$$\phi(r) = (2y - 1)/(2 - y) \tag{10}$$

and

$$\psi(r) = \left[\frac{2}{r(2-y)} \exp\left\{\int_{r_i}^{r} \frac{\phi(r)}{r}\, dr\right\}\right]^{1/n}, \tag{11}$$

$y$ being a function of the radius $r$ (or $x$ in the later treatment) of the disk. These two functions will be found very useful when the processes of the numerical integration for the power function relation are performed.

Integrating Eq. 7 between $r_i$ and $r_o$, we have the average tangential stress of disk

$$\sigma_{tav} = \frac{1}{A_0}\int_{r_i}^{r_o} \sigma_t h dr = (\rho\omega^2 I_0 + h_o r_o \sigma_{r_o} - h_i r_i \sigma_{r_i})/A_0 \tag{12}$$

in which $\sigma_{r_i}$ is to be determined and $\sigma_{r_o}$ can be calculated when the centrifugal forces of turbine rim and blades acting on the outer radius of disk are given. The others may be obtained from the given geometric conditions of disk.

Observe that for a solid disk integrated with a shaft, near the center or near the shaft, the tangential and radial stresses of the disk are approximately equal. Therefore, these stresses can be given by (see Appendix I)

$$\sigma_{t_i} \simeq \sigma_{r_i} = (\rho\omega^2 I_0 + h_o r_o \sigma_{r_o})/(h_i r_i + A_0). \tag{13}$$

Introducing this to Eq. 12, the average tangential stress which assumes a first approximation of $\sigma_t$, that is, $\sigma_{t_1}$, is found exactly the same as given by Eq. 13. Now, using $h = cr^m$ ($m$ is usually a negative value, so that it should be not applied at the disk center where it becomes a singular point), $r/r_o = x$ and $\rho\omega^2 r_o^2 = \sigma_c$, Eq. 13 for a first approximation of $\sigma_t$ may be expressed in the non-dimensional form

$$\frac{\sigma_{t_1}}{\sigma_{tav}} = \frac{\sigma_{t_i}}{\sigma_{tav}} = \left(\frac{1 - x_i^{m+3}}{m+3}\frac{\sigma_c}{\sigma_{tav}} + \frac{\sigma_{r_o}}{\sigma_{tav}}\right)(m+1)/(1 + mx_i^{m+1}) = 1. \tag{14}$$

To find a first approximation for $\sigma_r$, that is, $\sigma_{r_1}$, we substitute $\sigma_{tav}$ for $\sigma_t$ in Eq. 7 and integrate between $r_i$ and $r$; hence

$$\frac{\sigma_r}{\sigma_{tav}} = \frac{\sigma_{r_1}}{\sigma_{tav}}\left[(h_i r_i + A) - \frac{\rho\omega^2 I}{\sigma_{tav}}\right] = \frac{1}{x^{m+1}}\left[\frac{x^{m+1} + m x_i^{m+1}}{m+1} - \frac{x^{m+3} - x_i^{m+3}}{m+3}\frac{\sigma_e}{\sigma_{tav}}\right]. \quad (15)$$

Equations 14 and 15, therefore, furnish a first approximation of the stress distribution in disk by the power function relation.

To obtain a first approximation for $y$ for use in Eqs. 10 and 11 for a second approximation of $\sigma_t$ and $\sigma_r$, we divide Eq. 15 by Eq. 14, that is, $y_1 = \sigma_{r_1}/\sigma_{t_1}$, $y_1 = \sigma_{r_1}/\sigma_{t_1}$.

The equations for a second approximation of $\sigma_t$ and $\sigma_r$, that is, $\sigma_{t_2}$ and $\sigma_{r_2}$, are respectively given by (see Appendix I)

$$\frac{\sigma_t}{\sigma_{tav}} = \frac{\sigma_{t_2}}{\sigma_{tav}} = \frac{(h_i r_i + A_0)\psi(r)}{h_i r_i\left(\frac{2}{r_i}\right)^{1/n} + \int_{r_i}^{r} h\psi(r)dr} = \frac{\left(\frac{1 - x_i^{m+3}}{m+3}\frac{\sigma_e}{\sigma_{tav}} + \frac{\sigma_{r_o}}{\sigma_{tav}}\right)\psi(r)}{x_i^{m+1}(2/r_i)^{1/n} + r_o^{-(m+1)}\int_{r_i}^{r_o} r^m\psi(r)dr} \quad (16)$$

$$\frac{\sigma_r}{\sigma_{tav}} = \frac{\sigma_{r_2}}{\sigma_{tav}} = \frac{1}{hr}\left[(h_i r_i + A_0)\left\{h_i r_i(2/r_i)^{1/n} + \int_{r_i}^{r} h\psi(r)dr\right\} \Big/ \left\{h_i r_i\left(\frac{2}{r_i}\right)^{1/n} + \int_{r_i}^{r_o} h\psi(r)dr\right\} - \frac{\rho\omega^2 I}{\sigma_{tav}}\right]$$

$$= \frac{1}{x^{m+1}}\left[\left(\frac{1 - x_i^{m+3}}{m+3}\frac{\sigma_e}{\sigma_{tav}} - \frac{\sigma_{r_o}}{\sigma_{tav}}\right)(m+1)\frac{2^{1/n}x_i^{m-(1/n)+1} + r_o^{-(m-(1/n)+1)}\int_{r_i}^{r} r^m\psi(r)dr}{2^{1/n}x^{m-(1/n)+1} + r_o^{-(m-(1/n)+1)}\int_{r_i}^{r_o} r^m\psi(r)dr}\right.$$

$$\left. - \frac{x^{m+3} - x_i^{m+3}}{m+3}\frac{\sigma_e}{\sigma_{tav}}\right] \quad (17)$$

where

$$\left.\begin{aligned} A &= \int_{r_i}^{r} h dr = \frac{c}{m+1}(r^{m+1} - r_i^{m+1}), \quad A_0 = \int_{r_i}^{r_o} h dr = \frac{c}{m+1}(r_o^{m+1} - r_i^{m+1}) \\ I &= \int_{r_i}^{r} h r^2 dr = \frac{c}{m+3}(r^{m+3} - r_i^{m+3}), \quad I_0 = \int_{r_i}^{r_o} h r^2 dr = \frac{c}{m+3}(r_o^{m+3} - r_i^{m+3}) \end{aligned}\right\}. \quad (18)$$

It is easy to verify that at $r = r_i$ Eqs. 15, 16 and 17 will reduce identically to Eq. 13 or 14 which satisfies the stress condition, $\sigma_t \simeq \sigma_r$, near the center or near the integrated shaft of a rotating solid disk.

Substituting the value of $y_1$ into Eqs. 10 and 11, then, by numerical integration, $\sigma_{t_2}$ and $\sigma_{r_2}$ can be found from Eqs. 16 and 17, respectively. This completes the second approximation of stress distribution in the disk. Dividing $\sigma_{r_2}$ by $\sigma_{t_2}$, the second approximation for $y$, that is, $y_2$, can be found. The whole process is then repeated, using $y_2$ instead of $y_1$, to find a third approximation if required. Experience shows that the process converges not as rapidly as that for the disks with bore, but several approximations will give the desired stresses for practical use.

The stress distributions of the plain disk ($m = 0$) having $\gamma = 0.283$ lb per cubic in., $r_o = 10$ in., speed at 12,000 rpm., temperature at 1200° F. and $n = 6$ are calculated and plotted in Fig. 5. From Eq. 14, $\sigma_{tav} = 38{,}600$ psi. for $\sigma_{r_o} = 0$.

To obtain the relative creep rates and creep deformations, let $\dot{\epsilon}_{t_i}$ be

the creep rate and $\epsilon_{t_i}$ the creep strain at $r_i$ at time $t$, which is corresponding to the stress, $\sigma_{t_i}$. Then, from Eq. 8 for $y \simeq 1$, we have

$$\dot{\epsilon}_{t_i} = \tfrac{1}{2}k\sigma_{t_i}{}^n e^{-a/T} f(t), \quad \epsilon_{t_i} = \tfrac{1}{2}k\sigma_{t_i}{}^n \int_0^t e^{-a/T} f(t)dt \tag{19}$$

and

$$\left.\begin{aligned} \dot{\epsilon}_t/\dot{\epsilon}_{t_i} &= \epsilon_t/\epsilon_{t_i} = (2-y)(\sigma_t/\sigma_{t_i})^n \\ \dot{\epsilon}_r/\dot{\epsilon}_{t_i} &= \epsilon_r/\epsilon_{t_i} = (2y-1)(\sigma_t/\sigma_{t_i})^n \\ \dot{\epsilon}_z/\dot{\epsilon}_{t_i} &= \epsilon_z/\epsilon_{t_i} = -(\epsilon_t+\epsilon_r)/\epsilon_{t_i} \end{aligned}\right\} \tag{20}$$

where $\epsilon_{t_i}$ may be determined from creep test data or considered as the maximum allowable creep deformation at $r_i$ in creep design.

The relative creep strains of the disk from the preceding numerical example are given in Fig. 6 for the stresses of the third approximation.

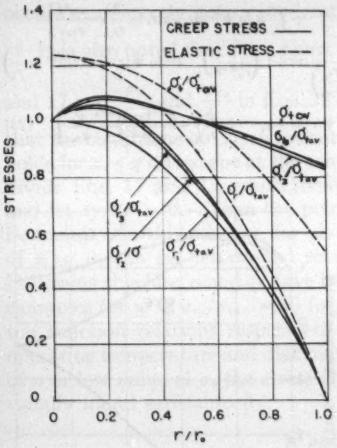



FIG. 5. The approximate stress distributions of the disk for the power function stress-creep-rate relation. $n = 6$.

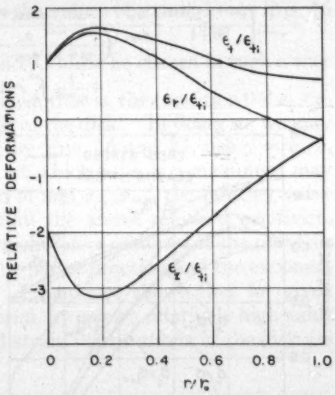



FIG. 6. The relative creep strains, corresponding to $\sigma_{r_i}$ and $\sigma_{t_i}$, of the disk for the power function stress-creep-rate relation. $n = 6$.

### (b) *Exponential Function Stress-Creep-Rate Relation*

As before, from Eqs. 9 the function

$$\Psi(r) = [\psi(r)]^n = \frac{2}{r(2-y)} \exp\left\{\int_{r_i}^{r} \frac{\phi(r)}{r}\, dr\right\} \tag{21}$$

is defined (see Appendix II), $\phi(r)$ remains the same as given in Eq. 10. In the same manner, we can obtain exactly the same expressions for $\sigma_{t_{av}}$, $\sigma_{t_2}$, $\sigma_{r_i}$, $\sigma_{t_1}$ and $\sigma_{r_1}$ as given, respectively, by Eqs. 12, 13, 14 and 15 for a first approximation of the stress distribution in the disk by the exponential function relation. Of course, the same expression for $y_1$ can be obtained for use in Eqs. 10 and 21 for a second approximation of the stress distribution of the exponential function relation.

Similarly, the expressions for a second approximation of $\sigma_t$ and $\sigma_r$, that is, $\sigma_{t_2}$ and $\sigma_{r_2}$, can be given, respectively, by (see Appendix II)

$$\frac{\sigma_t}{\sigma_{t_{av}}}=\frac{\sigma_{t_2}}{\sigma_{t_{av}}}=1-\frac{\sigma_0}{(h_i r_i+A_0)\sigma_{t_{av}}}\left[\int_{r_i}^{r_o} h\ln\Psi(r)dr-(h_i r_i+A_0)\ln\Psi(r)+h_i r_i\ln\frac{2}{r_i}\right]$$

$$=1-\frac{\sigma_0}{\left(\frac{1-x_i^{m+3}}{m+3}\frac{\sigma_c}{\sigma_{t_{av}}}-\frac{\sigma_{r_o}}{\sigma_{t_{av}}}\right)\sigma_{t_{av}}}\left[\frac{1}{r_o^{m+1}}\int_{r_i}^{r_o} r^m\ln\Psi(r)dr-\frac{1+mx_i^{m+1}}{m+1}\ln\Psi(r)+x_i^{m+1}\ln\frac{2}{r_i}\right] \quad (22)$$

$$\frac{\sigma_r}{\sigma_{t_{av}}}=\frac{\sigma_{r_2}}{\sigma_{t_{av}}}=\frac{1}{hr}\left[h_i r_i+A-\frac{\sigma_0}{\sigma_{t_{av}}}\left\{\frac{h_i r_i+A}{h_i r_i+A_0}\left(\int_{r_i}^{r_o} h\ln\Psi(r)dr+h_i r_i\ln\frac{2}{r_i}\right)\right.\right.$$

$$\left.\left.+\int_{r_i}^{r} h\ln\Psi(r)dr+h_i r_i\ln\frac{2}{r_i}\right\}-\frac{\rho\omega^2 I}{\sigma_{t_{av}}}\right]$$

$$=\frac{1}{x^{m+1}}\left[\frac{x^{m+1}-x_i^{m+1}}{m+1}-\frac{\sigma_0}{\sigma_{t_{av}}}\left\{\frac{x^{m+1}+mx_i^{m+1}}{\left(\frac{1-x_i^{m+3}}{m+3}\frac{\sigma_c}{\sigma_{t_{av}}}-\frac{\sigma_{r_o}}{\sigma_{t_{av}}}\right)}(m+1)\left(\frac{1}{r_o^{m+1}}\int_{r_i}^{r_o} r^m\ln\Psi(r)dr+x_i^{m+1}\ln\frac{2}{r_i}\right)\right.\right.$$

$$\left.\left.+\frac{1}{r_o^{m+1}}\int_{r_i}^{r} r^m\ln\Psi(r)dr+x_i^{m+1}\ln\frac{2}{r_i}\right\}-\frac{x^{m+3}-x_i^{m+3}}{m+3}\frac{\sigma_c}{\sigma_{t_{av}}}\right]. \quad (23)$$

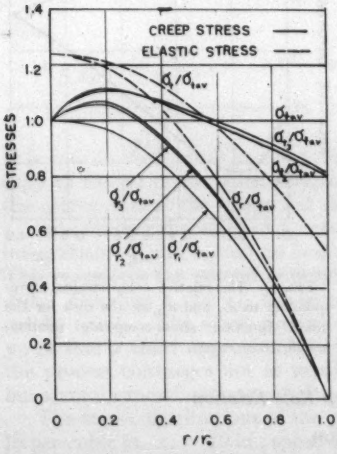



FIG. 7. The approximate stress distributions of the disk for the exponential function stress-creep-rate relation. $\sigma_0$ = 7000 psi.

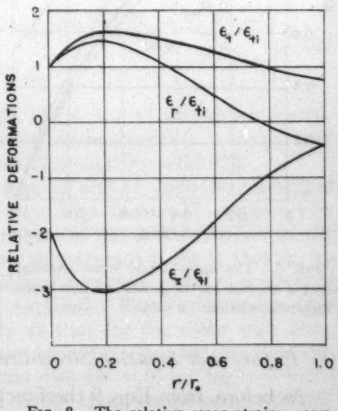



FIG. 8. The relative creep strains, corresponding to $\sigma_{r_2}$ and $\sigma_{t_2}$, of the disk for the exponential function stress-creep-rate relation. $\sigma_0$ = 7000 psi.

It can be verified that at $r = r_i$, Eqs. 22 and 23 will be reduced identically to Eq. 14 which satisfies the stress condition at the center or near the integrated shaft of a rotating solid disk.

The rest of the process for the successive approximation by numerical integration will be similar to what has been previously discussed for the power function stress-creep-rate relation.

For the purposes of a qualitative comparison, the stress distribution and relative creep strains for the exponential function, with the assumed value of $\sigma_0 = 7000$ psi. (approximately for 12 per cent Cr steel) and the other data given in the previous example, are computed and plotted in Figs. 7 and 8, respectively.

As a matter of fact, in order to save strategic material, an efficient disk design is generally required. In such case, the disk is usually operated at the condition of relatively high stresses. Therefore, the exponential function or hyperbolic sine creep law may be considered more important than the power function creep law which commonly occurs at relatively low or moderate stresses.

It is also noted that for a given $m$ the values of $n$ and $\frac{\sigma_{r_o}}{\sigma_{tav}}$ in Eqs. 16 and 17 and $\frac{\sigma_0}{\sigma_{tav}}$ and $\frac{\sigma_{r_o}}{\sigma_{tav}}$ in Eqs. 22 and 23 must be chosen in such a way that the conditions of Eqs. 6 are satisfied, that is, the condition $0 < \sigma_r < \sigma_t$ holds for $x_i < x < 1$ except at the center of the disk. In doing so, we may divide Eqs. 17 and 23, respectively, by Eqs. 16 and 22, use $y = \sigma_r/\sigma_t$ and let $dy/dx = 0$. Then the point at which $\sigma_r/\sigma_t$ is a maximum may be found. In this manner, for given $m$ and $\sigma_{r_o}/\sigma_{tav}$, the limiting value of $n$ or $\sigma_0$ can be determined to fulfill the above required condition. Following this line, $n$ and $\sigma_0$ have been chosen or assumed in the previous examples ($m = 0$, $\sigma_{r_o}/\sigma_{tav} = 0$) for the power function and the exponential function relations respectively. Experience shows that for given operating temperature and disk material, by using a relatively high value of $n$ or low value of $\sigma_0$ the stress and strain distributions in the disk are usually found satisfactorily.

### 6. DISCUSSIONS

Test data indicate that, in general, for a given material the "material creep number," $n$, depends mainly on stress and temperature and the "material creep modulus," $\sigma_0$, slightly on temperature (it appears to decrease with temperature). Figures 9 and 10, for example, show the plot of $n$ for molybdenum-vanadium and chromium-nickel-columbium steels at 0.001 creep strain respectively (16).

Theoretically, engineering material is customarily assumed to be isotropic. Actually, metals at high stresses and high temperatures usually display, more or less, the phenomenon of anisotropy. Further-

more, one of the turbine-disk failures is often caused by excessive creep deformations. As the maximum shear theory takes some anisotropic effects into consideration implicitly, it yields the larger creep deformations in excellent agreement with the creep test data and gives simpler

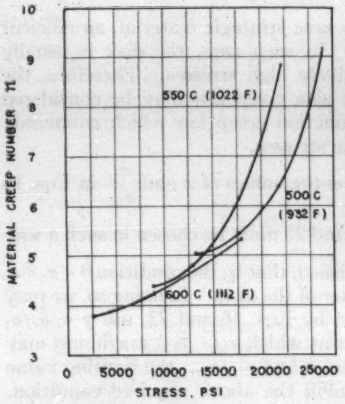
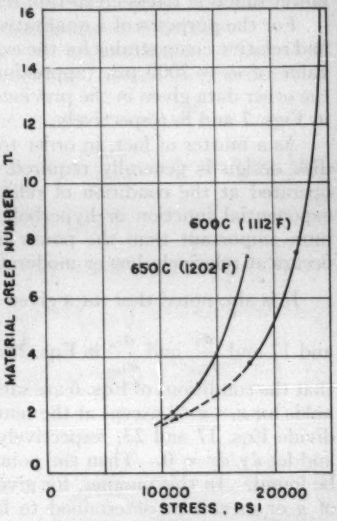



FIG. 9. The values of $n$ for Mo−V steel.




*Courtesy of the Institution of Mechanical Engineers*

FIG. 10. The values of $n$ for 18 per cent Cr, 9.5 per cent Ni and 1.2 per cent Nb steel.

stress and strain equations than the use of the distortion energy theory. Therefore, based on utility and accuracy, the maximum shear theory appears to be a comparatively simple and reasonable approach for practical turbine disk design.

*Acknowledgments*

The writer wishes to take this opportunity to express his deep appreciation to his inspiring and respected teachers. Acknowledgment is also made to his colleagues in the Department of Mechanical Engineering, South Dakota State College for their cooperation in preparing the work and to Mr. Phillip L. M. Ko for drawing the graphs.

## APPENDIX I

From basic assumption (*b*), the equation of incompressibility is given by

$$\epsilon_t + \epsilon_r + \epsilon_z = 0 \quad \text{or} \quad \dot{\epsilon}_t + \dot{\epsilon}_r + \dot{\epsilon}_z = 0. \tag{a}$$

The equations for creep strains and creep rates at radius $r$ of the disk are given by:

for the tangential component $\epsilon_t = u/r, \quad \dot{\epsilon}_t = \dot{u}/r$ (*b*)

for the radial component $\epsilon_r = \partial u/\partial r, \quad \dot{\epsilon}_r = \partial \dot{u}/\partial r$ (*c*)

and for the axial component, from Eqs. *a*, *b* and *c*

$$\epsilon_z = -(u/r + \partial u/\partial r), \quad \dot{\epsilon}_z = -(\dot{u}/r + \partial \dot{u}/\partial r). \tag{d}$$

Furthermore, by eliminating $u$ or $\dot{u}$ from Eqs. *b* and *c*, the equation of compatibility is obtained

$$\partial(r\epsilon_t)/\partial r - \epsilon_r = 0 \quad \text{or} \quad \partial(r\dot{\epsilon}_t)/\partial r - \dot{\epsilon}_r = 0 \tag{e}$$

which can be used to check the solutions for creep strains or creep rates if the equation of incompressibility is satisfied.

From Eqs. *b*, *c* and 8, we have

$$\dot{\epsilon}_t = \dot{u}/r = k\sigma_t^n(1 - y/2)e^{-a/T}f(t) \tag{f}$$

$$\dot{\epsilon}_r = \partial \dot{u}/\partial r = k\sigma_t^n(y - \tfrac{1}{2})e^{-a/T}f(t) \tag{g}$$

$$\dot{\epsilon}_r/\dot{\epsilon}_t = r\partial \dot{u}/\dot{u}\partial r = (2y - 1)/(2 - y) = \phi(r). \tag{10}$$

Integrating Eq. 10 between $r_i$ and $r$ and then dividing by $r$ yields

$$\dot{\epsilon}_t = \dot{u}/r = \frac{\dot{u}_i}{r} \exp\left\{\int_{r_i}^{r} \frac{\phi(r)}{r}\, dr\right\}. \tag{h}$$

Comparing this to the first of Eqs. 8 and solving for $\sigma_t$, we have

$$\sigma_t = [\dot{u}_i/kf(t)]^{1/n} e^{a/nT}\psi(r) \tag{i}$$

where $\psi(r)$ is defined in Eq. 11. Introducing $\sigma_t$ from Eq. *i* to Eq. 12,

$$[\dot{u}_i/kf(t)]^{1/n} e^{a/T} = A_0\sigma_{tav} \Big/ \int_{r_i}^{r_o} h\psi(r)dr. \tag{j}$$

Substituting this into Eq. *i*, the tangential stress in the disk is

$$\sigma_t = A_0\sigma_{tav}\psi(r) \Big/ \int_{r_i}^{r_o} h\psi(r)dr. \tag{14a}$$

Upon integration of (7) between $r_i$ and $r$, the radial stress in the disk is

$$\sigma_r = \frac{1}{hr}\left[\int_{r_i}^{r} h\sigma_t dr - \rho\omega^2 I + h_i r_i \sigma_{r_i}\right] \tag{15a}$$

where $\sigma_{r_i}$ as well as $\sigma_{tav}$ is still unknown.

Remember that when the disk is made integral with a shaft, near the center or close to the integrated shaft of the disk, $\sigma_t \simeq \sigma_r$, which is sufficiently accurate for all practical purposes. Now, in order to determine the value of $\sigma_{r_i}$, let us assume that $r_i \simeq r_o/10$ and $y \simeq 1$. Hence, from Eqs. 10 and 11, we have

$$\phi(r) \simeq 1 \tag{k}$$

and

$$\psi(r) \simeq (2/r_i)^{1/n}. \tag{l}$$

Substituting the latter into Eq. *i* gives

$$\sigma_{t_i} \simeq \sigma_{r_i} = [\dot{u}_i/kf(t)]^{1/n} e^{a/nT}(2/r_i)^{1/n}. \tag{m}$$

Introducing this to Eq. $j$ and using Eq. 12, we have

$$[\dot{u}_i/kf(t)]^{1/n}e^{a/nT} = \frac{\rho\omega^2 I_0 + h_0\sigma_{r_0}}{h_i\sigma_i(2/r_i)^{1/n} + \int_{r_i}^{r_0} h\psi(r)dr} \qquad (n)$$

Substituting this into Eq. $i$, the stresses at $r_i$ are thus determined as given in Eq. 13.

To find $\sigma_{t_2}$ for the power function relation, we use Eqs. $m$ and $n$. Solving for $[\dot{u}_i/kf(t)]^{1/n}$ and then introducing it to Eq. $i$, the tangential stress for a second approximation in the non-dimensional form is obtained (Eq. 16).

For $\sigma_{r_2}$, we substitute Eqs. $i$ and $m$ into Eq. 15$a$ and use the value of $[\dot{u}_i/kf(t)]^{1/n}$, whence Eq. 17 is also obtained.

## APPENDIX II

Similarly, from Eqs. $b$, $c$ and 9, we have

$$\dot{\epsilon}_t = \dot{u}/r = Ke^{\sigma_i/\sigma_0}(1 - y/2)e^{-a/T}f(t) \qquad (o)$$

$$\dot{\epsilon}_r = \partial\dot{u}/\partial r = Ke^{\sigma_i/\sigma_0}(y - \tfrac{1}{2})e^{-a/T}f(t) \qquad (p)$$

$$\dot{\epsilon}_r/\dot{\epsilon}_t = r\partial\dot{u}/\dot{u}\partial r = (2y - 1)/(2 - y) = \phi(r) \qquad (10)$$

and

$$\sigma_i = \sigma_0\left[\ln\frac{\dot{u}_i}{Kf(t)} + \ln\Psi(r) + \frac{a}{T}\right] \qquad (q)$$

where $\Psi(r)$, Eq. 21, is found from Eqs. $k$ and the first of Eqs. 9.

Introducing Eq. $q$ to Eq. 7 and using Eq. 12, we have

$$\ln[\dot{u}_i/Kf(t)] + a/T = \frac{\sigma_{t_0 T}}{\sigma_0} - \frac{1}{A_0}\int_{r_i}^{r_0} h\Psi(r)dr. \qquad (r)$$

Following the method used in Appendix I, we have

$$\sigma_{t_i} \simeq \sigma_{r_i} = \sigma_0\left[\ln\frac{\dot{u}_i}{Kf(t)} + \frac{a}{T} + \ln\frac{2}{r_i}\right] \qquad (s)$$

and exactly the same expressions of Eqs. 14 and 15 for $\sigma_{t_1}$ and $\sigma_{r_1}$, respectively, and also for the exponential function relation.

To find $\sigma_{t_2}$ in the disk for a second approximation of the exponential function relation, first, use Eqs. 12, 13 and $s$ to obtain the value of $\ln[\dot{u}_i/Kf(t)]$, then introduce this value to Eq. $q$, and, finally, we obtain Eq. 22 for $\sigma_{t_2}$ in the non-dimensional form.

Similarly, for $\sigma_{r_2}$, we introduce Eqs. $q$ and $s$ to Eq. 15$a$ and use the value of $\ln[\dot{u}_i/Kf(t)]$, to obtain Eq. 23.

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**Ion Rocket Engine.**—A rocket engine to create ions and harness them for propulsion will work this way: It will employ a chemical propellant whose molecules offer the highest possible weight. Among "ideal" propellants are uranium tetrachloride, thorium, mercury and the alkali metals, cesium and rubidium.

Vaporized, the propellant will be fed into an electrically charged chamber. There an electric arc or a metallic plate generating 100 times the heat of a large electric stove will knock loose an electron from each molecule of vaporized propellant. In losing an electron, each molecule will assume a positive charge and its remaining bulk thus becomes an ion.

The newly created ions will be pulled out of the ionizing chamber by the attraction of an electrostatic field and then jolted by 12,000 volts to effective velocities of 300 to 400 thousand miles an hour.

The current of speeding ions—a million times greater in number and 350,000 times heavier than the stream of electrons in a TV picture tube—will be harnessed for propulsion by being directed through a cylindrical thrust chamber approximately two feet long and nine inches in diameter. Propulsive force will come from the vehicle's reaction to the escape of ions from the chamber.

Of little use to the system, electrons left over from the ionization process also will be directed through a thrust chamber to add a tiny increment of additional thrust.

**Wall-Mounted Tensile Tester.**—Because bench space is frequently at a premium in test locations, Steel City Testing Machines, Inc., Detroit, Mich., now makes available a wall-mounted tensile tester. The hydraulic cylinder and jaw units, and the 8½-in. gage can be mounted on the wall. The only bench space required is for the 3 × 8 in. pump and integral reservoir base, and the manual pumping handle, which extends forward 8½ in.

Tests can be made on flat or round specimens with sufficient accuracy for laboratory use and simply enough for production use. Test specimens—weld samples, cast coupons, etc.—are gripped by hardened and ground jaws that are wedge type to insure positive grip. Initial gripping force is applied by manually tightening adjusting screws. As pressure for the test builds up, the wedge shape of the jaws increases the holding force.

The stationary jaw holder can be adjusted for specimens from 5 to 13 inches long. The jaw holder is held in place by half rings and grooves, and is located by a non-load-carrying lock screw.

This tester can be checked easily with a compression-type proving ring. The top jaw-adjusting screw is simply removed and the proving ring is placed between the moving jaw and the cylinder body.

Breaking or yield point is indicated by a maximum-pointer hand that is carried along by the pressure hand on the gage. Models are available with capacities up to 40,000 pounds.

# THE FRANKLIN INSTITUTE

## MINUTES OF THE ANNUAL MEETING

**January 21, 1959**

The Annual Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. Mr. Wynn Laurence LePage, President, called the meeting to order with approximately 320 members and guests in attendance.

The President stated that the minutes of the Stated Meeting held on November 19, 1958 were printed in the December issue of the JOURNAL. There being no corrections or additions, the minutes were approved as published. He then announced that the minutes of the Stated Meeting of December 17, 1958 will be printed in the January, 1959, issue of the JOURNAL and will be presented for approval at the next Stated Meeting.

Mr. LePage called on Dr. Joseph S. Hepburn, one of the Tellers, for the report of the Tellers of Election, appointed in accordance with the By-Laws to count the votes for ten Managers to be elected. Dr. Hepburn reported that 1611 ballots were cast of which 1358 were legal and 253 defective, and the nominees received votes as follows:

| | | | |
|---|---|---|---|
| Henry B. Allen | 1269 | R. G. Rincliffe | 1259 |
| G. H. Clamer | 1226 | James H. Robins | 1241 |
| A. Felix duPont, Jr. | 1252 | Herbert H. Swinburne | 914 |
| J. G. R. Heckscher | 1229 | Philip H. Ward, Jr. | 1236 |
| Clarence L. Jordan | 1268 | Harleston R. Wood | 1172 |
| Lionel F. Levy | 1110 | | |

The President then declared the following ten members were thereby elected Managers of the Institute for a term of three years:

| | |
|---|---|
| Henry B. Allen | Lionel F. Levy |
| G. H. Clamer | R. G. Rincliffe |
| A. Felix duPont, Jr. | James H. Robins |
| J. G. R. Heckscher | Philip H. Ward, Jr. |
| Clarence L. Jordan | Harleston R. Wood |

Mr. LePage thanked Dr. George S. Crampton, Dr. Joseph S. Hepburn and Mr. Howard Stoertz for their services as Tellers of Election.

The President called upon the Executive Vice President to read the report submitted by the Trustees of the Elliott Cresson Medal Fund showing the financial transactions for the year, which, in accordance with the Deed of Gift that forms the basis of the Award, must be presented at the Annual Meeting of The Franklin Institute. The report follows:

## ELLIOTT CRESSON MEDAL FUND

Report of the Trustees to The Franklin Institute

January 21, 1959

PRINCIPAL

| | | |
|---|---|---|
| *Principal of the Fund* (representing the original $1,000 plus transfers thereto from Unexpended Income and profit from disposition of investments) | | $4,304.73 |
| Invested as follows: | | |
| $4,000 U. S. Treasury 2½% bonds, due 6/15/1962–67 at book value | $4,055.35 | |
| Cash in Western Savings Fund Society | 249.38 | |
| | $4,304.73 | |

INCOME

| | | |
|---|---|---|
| *Income of the Fund for 1958* | | |
| Interest on bonds (less amortization) | $ 126.29 | |
| Interest on bank balance | 6.96 | $ 133.25 |
| *Expenses* | | |
| Medals, certificates and cases | | 203.27 |
| *Expenses in excess of Income for the year 1958* | | $ (70.02) |
| *Unexpended Income at January 1, 1958* | | 2,237.01 |
| *Unexpended Income at December 31, 1958* | | $2,166.99 |
| Invested as follows: | | |
| $2,000 U. S. Treasury 2½% bonds, due 6/15/1962–67 at book value | $2,027.82 | |
| Cash in Fidelity-Philadelphia Trust Co. | 139.17 | |
| | $2,166.99 | |

*/s/ Henry B. Allen*
HENRY B. ALLEN

*/s/ John Frazer*
JOHN FRAZER
*Trustees*

The President stated that the Annual Report of The Franklin Institute will be published in the April issue of the JOURNAL and a copy of the report will be mailed to members of the Institute. He presented a summary of this report which had been approved by the Board of Managers.

The President then announced that he took considerable pleasure in introducing the speaker of the evening, Dr. Rene J. Dubos, a Member and Professor of the Rockefeller Institute for Medical Research, an internationally famous bacteriologist, and a distinguished lecturer, whose subject was "The Response of Man to His Total Environment."

In speaking of man and his relation to past and present environment, Dr. Dubos traced the effects of man's environment, both of his own creation and by the hand of nature, in disease, nutrition and society, from the past to the present, projecting the capabilities of man and what he could do to alter his environment or himself so that human life can continue and thrive on this planet.

After an interesting and provocative discussion period, Mr. LePage thanked Dr. Dubos for his outstanding talk.

Mr. LePage adjourned the meeting at 9:40 P.M. with a rising and enthusiastic vote of thanks to Dr. Dubos by the audience.

WILLIAM F. JACKSON, JR.
*Secretary*

## COMMITTEE ON SCIENCE AND THE ARTS

*(Abstract of Proceedings of Stated Meeting held Wednesday, January 14, 1959.)*

HALL OF THE COMMITTEE,
PHILADELPHIA, JANUARY 14, 1959.

MR. JOSEPH GRAY JACKSON in the Chair.

The following reports were presented for final action:

No. 3338: Application of the Rocket Jet to Mining and Quarrying.

This report recommended the award of a John Price Wetherill Medal to Robert B. Aitchison, of Newark, New Jersey, "In consideration of his initiation, development and practical application of the jet-piercing process as applied to open-pit mining and quarrying and the economic importance of this development to the steel industry and to the nation."

No. 3352: Brown Medal.

This report recommended the award of the Frank P. Brown Medal to Hardy Cross, of Virginia Beach, Virginia, "For his outstanding career as a teacher, especially of engineering students during the past fifty years at Hampden-Sydney College, Brown University, the University of Illinois and Yale University; for his many contributions to professional publications during this time; and finally, for his original and later supplementary papers on the Moment-Distribution Method of analyzing indeterminate structures."

D. S. FAHRNEY,
*Secretary to Committee*

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## LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 661 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

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## MEMBERSHIP

The following elections were approved on January 8, 1959 by the Membership Committee by authority given to it by the Board of Managers.

ANNUAL

John M. Ashe
John C. Barringer
Martin L. Beller
Nelson Bolton
George Fairburn Brett
G. Edmond Capuano
Alfred D. Chandler
Harold B. Collins, Jr.
Winfield C. Cook
Bertram Copenhaver
Jeanne Faith Coryell
Mrs. Townsend King Davis
J. Pieter de Vries
Richard C. du Pont, Jr.
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Marvin P. Feyerherm
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Ben Goodman
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Ralph T. Hanna, Jr.
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Glenn J. Hoffman
John J. Hohenadel
Steven M. Horvath
Edward J. Hurys
Edward L. Irwin
Beryl Jaffee
Charles M. James
Robert B. Janes
John T. Jones, Jr.
John T. Keating
Peter F. Kelly
Charles W. Lofft, Jr.
John W. McCaskey, Jr.
Allan G. Mitchell
John P. Poth
Mel Richman
Kaare Rodahl
John E. Rutledge, Jr.
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G. William Sickel
Leonard Smidth
William Sonstein
Leon Sunstein, Jr.
Douglas S. Valentine
Herman B. Wagner
Lawrence S. Warren
Harleston R. Wood
Edgar E. Wrege

EDUCATOR

John Burrowes
Saul Gorn
Robert J. Heacock
Mary McCay
Jane M. Nash
Perry Polss
Claire M. Strong
Jesse Bitler Zerr

NON-RESIDENT

Marvin Fox

NECROLOGY

Thomas J. Bagley '46
Frank B. Bower '36
W. H. Fulweiler '11
Charles F. Kettering '36
Blanche F. Kleiner '49
Wolfgang Pauli '52
Walter M. Schwartz '37
Frederic H. Strawbridge '36
William Zentmayer '44

# BOOK REVIEWS

HANDBOOK ON TORSIONAL VIBRATION, compiled by E. J. Nestorides. 664 pages, diagrams, 6 × 9 in. New York, Cambridge University Press, 1958. Price, $19.50.

This book is published under the auspices of the British Internal Combustion Engine Research Association (BICERA) consisting of 21 firms engaged in the manufacture of this equipment for general use, but primarily for ship propulsion. The Association's work is under the direction of a panel of 17 persons all members of the staff of the sponsoring firms, and it is done in a research laboratory where the author of this book is engaged.

It is a true handbook covering all aspects of the subject of designing and measuring torsional vibration in internal combustion engine systems in great detail. For example there are twenty different formulae for the stiffness of a crank-shaft, which were published over the years. Every one of these is discussed with an example. The great value of the book lies however in the one recommended BICERA formula, which is an empirical one embodying the pooled experience over many years by all the member firms. A similar situation exists with respect to the predicted amplitude of vibration for engine systems without dampers for which 14 formulae are listed and explained, some dating back more than 25 years. However a new BICERA formula is proposed which is based on extended experience and distinguishes the effects of counterweights, auxiliary drives and number of cylinders, which was never done before.

The book contains extensive chapters on propeller damping, on various types of dynamic and friction dampers and on the characteristics of available instrumentation. It will be used as a valuable reference for designers of this type of equipment. For the study of the subject by a beginner or by a nonspecialized engineer it is too large and too detailed.

J. P. DEN HARTOG
*Massachusetts Institute of Technology*

QUANTUM MECHANICS OF ONE- AND TWO-ELECTRON ATOMS, by H. A. Bethe and E. E. Salpeter. 368 pages, diagrams, 6½ × 9½ in. New York, Academic Press, Inc., 1958. Price, $10.00.

This book is taken almost wholly from an article prepared in 1956 for the new edition of the "Handbuch der Physik" and is based on a translation, by Norbert Rosenzweig, of the well known classic in the literature of quantum mechanics—the article by Bethe in the 1932 edition of the "Handbuch." The book is at once a reference work for quantum mechanical calculations on hydrogen- and helium-like atoms (including comparisons of theoretical predictions and experimental results) and a source of materials for the study of applied quantum mechanics. Numerous approximation methods which may be employed much more generally than to the problems treated in this book are taken up in considerable detail.

The original article has been brought up-to-date by the inclusion of many new calculations and approximation methods relative to the original problems, by a more extended treatment of the Dirac theory and relativistic effects, and by the inclusion of radiative corrections—particularly of the Lamb shift. Of course it has not been possible to be completely exhaustive in the presentation; often calculations together with results are broadly sketched and references to original sources and secondary materials are given. This is particularly true in the section on radiative corrections in which a rather extensive literature has been summarized in a relatively short space.

It hardly needs saying that every theoretical physicist will want to know and use this book. It should be invaluable to all students of advanced quantum mechanics.

The book is a product of Springer-Verlag. To my mind the technical composition by this company is unsurpassed anywhere.

LEONARD EISENBUD
*State University College on Long Island*

NETWORK SYNTHESIS, by Norman Balabanian, 433 pages, diagrams, 6 × 9 in. Englewood Cliffs (N. J.), Prentice-Hall, Inc., 1958. Price, $12.00.

By its very nature network synthesis tends to be a graduate subject in most schools. Professor Balabanian's book is clearly written for this level and does not occupy many of its pages with the introductory "review" of mathematics or fundamental techniques. On the contrary, transform methods are employed from page 2 forward as the author addresses immediately the task of one-port synthesis.

By way of recent background this reviewer was privileged to examine Professor E. A. Guillemin's new book, "Synthesis of Passive Networks." Guillemin is probably the leading authority on network synthesis, his numerous books and papers having become conspicuous standards. It is interesting to compare the two books because both treat very nearly the same area. Whether this is or is not good etiquette in a book review, it may be of benefit to workers in the electrical network field.

When preparing to write a book on network synthesis one must rigidly restrict himself to some particular aspects of the subject, for it is so broad. This is truly an area for the specialist who is a strong man of mathematics. Success depends largely upon casting problems of network realization against a vast background of mathematics. The applications are largely to be found in communications and servomechanisms, although they are not discussed in the text.

Breakthroughs in network synthesis have occurred more or less at regular intervals over the recent decades. In the books by Professors Guillemin and Balabanian the names of many who have made such specific breakthroughs appear: Brune, Cauer, Cauchy, Darlington, Miyata, Ozaki, Dasher, Fialkow, etc. The task of covering these works is essentially what Professor Balabanian has accomplished in his book. In its introduction to the subject of network synthesis and in providing material for a good course of instruction it is a thoroughly adequate book.

By comparison Professor Guillemin's book is quite different. This is because the two men occupy different positions in the field. Professor Balabanian is a young man getting started in circuit theory; Professor Guillemin has written numerous books on the subject and has spent a lifetime developing his specialty. This is pointed up merely to distinguish among the books that are available the general nature of their contents: Balabanian's book for good general coverage of network synthesis; Guillemin's works for the more extensive study by the person who is making a career of the subject. The former can provide a satisfactory experience when studied alone. The latter cannot, for this would correspond to examining only one part of a fine painting in detail.

C. W. HARGENS
*The Franklin Institute Laboratories*

ROCKET TO THE MOON, by Erik Bergaust and Seabrook Hull. 270 pages, illustrations, 5¾ × 8¼ in. Toronto, New York and London, D. Van Nostrand Co., Inc., 1958. Price, $5.95.

There was a time when the concept of a rocket ascending to altitudes of 100 miles staggered the imagination; books that dealt with the theme of space travel were considered science fiction and thus slightly disreputable; and the prospects of satellites circling the Earth were considered sheer fantasy. That time has gone. Today the heads of States speak about satellites, space ships and space travel in the same breath with which they discuss the economic picture. Space travel has become respectable and what is more important, it is accepted. Today we no longer ask how or why; today we ask when.

Against this background has appeared a book on the conquest of the moon. The authors of *Rocket to the Moon* are Erik Bergaust and Seabrook Hull. Bergaust is Executive Editor of the magazine *Missiles and Rockets*, a magazine born of and dedicated to the space age, and Hull was a colleague of his until quite recently.

Across the desk of the authors have come concepts, studies and reports from research laboratories in this country and from abroad. These men have been able to assess the latest developments in the field and fit them in the proper niche. For this reason they have seen a pattern unfolding in which the goal was a manned landing on the moon.

Essentially their book is the unfolding of this pattern.

The authors have skillfully pieced together

the information at their disposal to present a story of how we will get to the moon and what we do after we get there. In a short review of this type it is impossible to delineate the various facets of this story. However, to this reviewer the most significant part of the book is the exposition concerning the ability of man to support himself on the moon.

The reviewer has spent considerable time in a study on a closed ecological cycle on the moon. The material presented here has the reviewer's complete confidence. Nothing is contained herein to which he would object. The authors have performed a masterful job of writing in this presentation.

The authors conclude their book with a superb description of the launching of the Air Force's first Thor-Able moon probe. Into this chapter is presented the finest description of a rocket take-off this reviewer has ever read. To read this chapter, and this reviewer read it twice, is to live through the critical moments of the launching. It brings home with startling reality the incredibly complex sequences which must be mastered and fitted into their proper chronological order before a device of this type can rise into the sky. Even if you could go to Cape Canaveral you still will not see or participate in the experience described. This is magnificent exposition.

*Rocket to the Moon* is highly recommended.

I. M. LEVITT
*Fels Planetarium, The Franklin Institute*

CONFERENCE ON EXTREMELY HIGH TEMPERATURES, edited by Heinz Fischer and Lawrence C. Mansur. 258 pages, illustrations, 8½ × 11 in. New York, John Wiley & Sons, Inc., 1958. Price, $9.75.

This is a compilation of papers presented at the Conference on Extremely High Temperatures held at Boston on March 18–19, 1958, under the sponsorship of the Air Force Cambridge Research Center, Electronics Research Directorate. The papers represent some of the latest developments in plasma analysis and in the production and measurement of temperatures up to millions of degrees, with emphasis on the relation of these developments to the propulsion field. The editors have both been on the staff of AFCRC for about ten years. The contributors represent more than a dozen industrial, government and university laboratories of this country, and two German sources. The important work of some laboratories in this field, however, is notable by its absence.

Although most of the papers present experimental results which are correlated with theory, some are primarily theoretical. Several are limited to descriptions of apparatus. A few are almost void of useful information (in one case only the abstract is given). The writing is generally satisfactory, but the quality varies considerably, as is to be expected in such a volume. One paper seems to be no more than a transcription of a tape recording; and one very thorough paper seems to suffer somewhat from editorial deletions.

The quality of the printing and the reproduction of figures and photographs are excellent. There are some minor typographical errors, whose correction is usually obvious.

The papers are distributed among four headings. The first, "The Production of Extremely High Temperatures," includes papers on experimental techniques involving magnetic acceleration, the upper temperature limits in the high-pressure discharge, the effects of electrically exploded wires and the ensuing discharge, an analysis of the direct current arc, and inductive storage of energy in the multi-million joule range as a tool for high temperature research. Under the second heading, "Methods of Temperature Measurement—Optical Radiation," there is a paper which describes the spectroscopic determination of plasma temperature using the Holtsmark theory of spectral line broadening, and another which presents objections to use of the Holtsmark theory. Other papers in this group discuss a thermometer for millions of degrees, the effects of radiation on the Rankins-Hugoniot shock conditions, and some calculations of the radial distribution of photon emitters in symmetric sources. Papers under the third heading, "Plasma Analysis," include a mathematical analysis of thermal diffusion in ionized gases and a detailed treatment of the stochastic foundation of the generalized macroscopic equations of change in a reacting plasma. Experimental papers in this group describe several types of plasma motors; the design of a megatron, a plasma wind motor in which a gas is accelerated by ions in crossed electric and magnetic

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fields. Of the final group on "Applications," one paper discusses the feasibility of using fusion reaction in thermonuclear propulsion for practical space travel. Other papers discuss the acceleration of plasma produced by the wire explosion technique along copper rod and aluminum plate guides, a gas stabilized arc for generating clean plasma, the behavior of materials subjected to the high temperatures of a water stabilized arc, and finally a discussion of the heating and mechanical limitations to the production of high magnetic fields and the interesting possibility of overcoming these in force-free coil designs.

The book will be useful to those groups which are engaged in research on the above subjects.

S. P. CARFAGNO
*The Franklin Institute Laboratories*

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## PUBLICATIONS RECEIVED

SEWERAGE AND SEWAGE TREATMENT, by Harold E. Babbitt and E. Robert Baumann. Eighth edition, 790 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1958. Price, $10.75.

ORDINARY DIFFERENTIAL EQUATIONS, by Wilfred Kaplan. 534 pages, 6 × 9 in. Reading (Mass.), Addison-Wesley Publishing Co., Inc., 1958. Price, $8.50. (Available in USA and Canada only.)

CREATIVE THINKING, by Charles S. Whiting. 168 pages, 5 × 7¼ in. New York, Reinhold Publishing Corp., 1958. Price, $3.95.

THE HEALTH OF A NATION, by Oscar E. Anderson, Jr. 333 pages, 6 × 9 in. Chicago, The University of Chicago Press, 1958. Price, $6.00.

TRANSISTORS. THEORY AND PRACTICE, by Rufus P. Turner. Second edition, revised, 5½ × 8½ in. New York, Gernsback Publications, Inc., 1958. Price, $2.95 (paper).

QUANTUM ELECTRODYNAMICS, edited by Julian Schwinger. 34 selected papers published for the first time in collected form (English, French and German), 424 pages, 6 × 9 in. New York, Dover Publications, Inc., 1958. Price, $2.45 (paper).

AUDIO MEASUREMENTS, by Norman H. Crowhurst. 223 pages, illustrations, 5½ × 8½ in. New York, Gernsback Library, Inc., 1958. Price: $2.90 (paper); $5.00 (hard cover).

SERVICING TRANSISTOR RADIOS, by Leonard D'Airo. 224 pages, illustrations, 5½ × 8½ in. New York, Gernsback Library, Inc., 1958. Price: $2.90 (paper); $4.60 (hard cover).

## BOOK NOTES

SYNTHESIS OF LINEAR COMMUNICATION NETWORKS, VOLS. I AND II, by Wilhelm Cauer. Second edition, edited by Wilhelm Klein and Franz M. Pelz and translated from the German by G. E. Knausenberger and J. N. Warfield. 866 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $19.50.

This translation of the 1941 German work "Theorie der linearen Wechselstromschaltungen" will be welcomed by English-speaking engineers who want a really complete reference book on network theory. The English version is an edited and expanded translation of the second revised German edition, with a section on recent advances added.

The translation is divided into two volumes, bound together. Volume I, which is a basic exposition of network analysis and synthesis, contains seven chapters and two appendices. It includes a discussion of the image-parameter method, as well as filter design, complete with tables, charts and examples. Volume II discusses the insertion-parameter design method, band-separation networks and network equivalence. Appendices give the mathematical foundations of circuit theory, and a review of the latest developments since Cauer's untimely death at the end of World War II.

The book is suitable for the electrical engineer and the physicist, in terms of the technical problems involved, and to the mathematician because of his interest in applications.

ELEMENTARY MATHEMATICAL PROGRAMMING, by Robert W. Metzger. 246 pages, 5¾ × 9 in. New York, John Wiley & Sons, Inc., 1958. Price, $5.95.

The author, supervisor of Mathematical Programming in the Industrial Engineering Department of the General Motors Institute, has prepared an elementary description of several mathematical programming methods. He has done this to bridge the gap between the existing texts which are either too technical or too nontechnical to be of use except to the mathematician in one case and management consultants in the other. This book is intended to serve both business and industry, as well as students in introductory courses in either mathematical programming (as a text) or operations research (as supplementary reading). The approach is a step-by-step one, with examples chosen from actual situations. The text, used and "debugged" in a class at General Motors Institute, contains eleven chapters on various methods of programming and their applications, a 5-page bibliography and an index.

ELEMENTARY MATRIX ALGEBRA, by Franz E. Hohn. 305 pages, 6 × 9¼ in. New York, The Macmillan Co., 1958. Price, $10.00.

The material herein presented is aimed primarily at undergraduate students in nearly all the physical sciences, engineering disciplines and the social sciences. The link which makes such a small text useful in so many fields is the growing tendency to use matrix algebra as a mathematical tool. The author's main purpose is to furnish the essentials of the method as simply and logically as possible, so that each individual may be prepared to apply the techniques to his own specialty. Specific examples, some completely worked out, add to the value of the book. The exercises vary from simple to complex and, in general, represent definite applications in a particular field, although their solution does not depend on a knowledge of that field. Prerequisite for the course is elementary college algebra.

NUCLEAR REACTORS FOR POWER GENERATION, edited by E. Openshaw Taylor. 144 pages, illustrations, 5½ × 8½ in. New York, Philosophical Library, 1958. Price, $7.50.

An up-to-date survey of the most important aspects of nuclear power generation is pro-

vided in this text. Based on an advanced lecture course delivered at Heriot-Watt College in Scotland, the book devotes separate sections to nuclear physics, types of reactor, physical basis of reactor design, safety and instrumentation, world energy requirements and nuclear energy programs. Information on the latest developments in the expanding and vitally important field of nuclear power generation is provided.

FUNDAMENTALS OF DIGITAL COMPUTERS, by Matthew Mandl. 297 pages, illustrations, 6 × 9 in. Englewood Cliffs (N. J.), Prentice-Hall, Inc., 1958. Price, $9.00.

Explanations of all the basic factors involved in the production, operation and maintenance of digital computers is the theme of this book. The author explores all the intricacies of computers and presents them in language free of highly technical terminology. Important fundamentals such as computer arithmetic applications, binary counting and special codes are discussed in detail as well as computer programming.

PERKIN CENTENARY LONDON. 100 YEARS OF SYNTHETIC DYESTUFFS. 136 pages, plates, 5½ × 8½ in. New York, London, Paris and Los Angeles, Pergamon Press Inc., 1958. Price, $7.50.

The four lectures contained in this volume were delivered in 1956 as a tribute to William Henry Perkin on the 100th anniversary of his discovery of synthetic organic dyes. A foreword by Sir Robert Robinson gives the history of the Perkin Centenary. John Read's paper on "The Life and Work of Perkin" sets forth Perkin's achievements; Clifford Paine then discusses developments in the dyestuffs industry since 1856; "The Tinctorial Arts Today" is the subject of the third lecture by John Gwynant Evans; and Sir Alexander Todd's "The Development of Organic Chemistry since Perkin's Discovery" concludes the series. The volume ends with a tribute to Perkin, proposed by the Marquess of Salisbury at the final banquet of the Centenary.

MICROCOSMAL PARTICLES AND PROTEIN SYNTHESIS, edited by Richard B. Roberts. 168 pages, illustrations, 6 × 9 in. New York and London, Pergamon Press Inc., 1958. Price, $5.00.

This volume contains the twenty papers presented at the First Symposium of the Biophysical Society, held in February, 1958. The subject was chosen because it allowed participation by X-ray diffractionists, electron microscopists, chemists and physicists. In addition, the subject is timely, involving recent discoveries about RNA and RNP. The papers deal with methods of isolation, size, composition and stability of the particles. New facts on particle-size variation and new methods of approach were presented, making it advisable for those engaged in protein synthesis research programs to study these papers at once.

FOUNDATIONS OF INFORMATION THEORY, by Amiel Feinstein. 137 pages, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $6.50.

This volume gives a concise but rigorous exposition of the fundamentals of the mathematical theory of information. Treated in detail, the subject is developed *ab initio*. The text is divided into two distinct branches. The first deals with the general properties of channels of various types, proving various theorems concerning their suitability for transmitting information. The second covers the actual implementation of those general theorems. The theme of Chapters 1–4 and 7 is the probability theory of finite systems. Chapter 5 deals with the semi-continuous channel without memory and Chapter 6 discusses the discrete channel with memory.

THE SCIENCE OF PHOTOGRAPHY, by H. Baines. 319 pages, illustrations, 5½ × 8½ in. London, Fountain Press; New York, John Wiley & Sons, Inc.; 1958. Price, $7.50.

This text is intended primarily for the non-scientist interested in photography. It begins with the evolution of the camera and the photographic processes. Presented in language comprehensible to the average photographer and completely non-mathematical, the

author covers subjects such as latent image theory, the mechanism of development, reciprocity failure and color masking. The serious photographer will welcome this complete treatise on the subject.

PRINCIPLES OF QUANTUM ELECTRODYNAMICS, by Walter E. Thirring. Translated from the German by J. Bernstein. 234 pages, 6 × 9 in. New York and London, Academic Press Inc., 1958. Price, $8.00.

Although originally written six years ago, the German edition of this book was not published until 1955. The translator has revised and expanded the original text, incorporating recent contributions which have not been treated in Jauch and Rorhlich's "The Theory of Photons and Electrons" (1955) and Umezawa's "Quantum Field Theory" (1956). In particular, Chapter 14 on Renormalization Theory has been given a more elaborate treatment. The English text will be welcomed by physicists seeking a better understanding of quantum electrodynamic theory, for the author emphasizes the physical basis of the theory, avoiding an excess of mathematical formalism.

THE PHYSICAL CHEMISTRY OF STEELMAKING, edited by John F. Elliott. 257 pages, illustrations, 8½ × 11 in. New York, John Wiley & Sons, Inc., and The Technology Press; London, Chapman & Hall Ltd.; 1958. Price, $15.00.

This volume contains the 36 papers, 7 discussions and one lecture presented at the Conference on the Physical Chemistry of Iron and Steelmaking held at MIT in 1956. Among the subjects covered are liquid metals and their properties, equilibria of reactions, behavior of metal oxides, slag-metal equilibria and reactions, process development, and solidification of castings and ingots. The seven discussions are brief summaries of comments offered in a session on research planning.

OPERATIONS RESEARCH FOR INDUSTRIAL MANAGEMENT, by Dimitris N. Chorafas. 303 pages, 6 × 9 in. New York, Reinhold Publishing Corp., 1958. Price, $8.75.

In this book the author describes the use of electronic computing in such management fields as financial allocation, transportation problems, inventory control and production set-up. Along with these applications of operations research techniques, the author covers game theory, mathematical models for simulation, linear programming, matrix analysis and flow techniques. By presenting both applications and theory, the author has widened his potential audience to include both management and technical personnel, such as systems engineers and computer technologists.

ANNUAL REVIEW OF NUCLEAR SCIENCE. Volume 8. 1958, edited by E. Segrè. 417 pages, diagrams, 6 × 8¾ in. Palo Alto (Calif.), Annual Reviews, Inc., 1958. Price: $7.00 (USA); $7.50 (foreign).

Volume 8 in this series comprises thirteen review papers on widely varying facets of nuclear science. Two papers deal with radiobiology, but one treats cellular radiobiology and the other, the application of information theory to that special field. The other papers deal with invariance principles, the optical model, hyperfragments, antinucleons, gamma-ray spectroscopy, advances in accelerator design, primary cosmic radiation, radioactivity of the atmosphere and hydrosphere, geochronology, nuclear astrophysics and control of radiation hazards in physics research.

COMPACT HEAT EXCHANGERS, by W. M. Kays and A. L. London. 156 pages, diagrams, 8½ × 11 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $6.00.

The important data from 22 ONR reports covering results of experimental and analytical work at Stanford on compact heat transfer surfaces are summarized in this volume. In addition, it includes data from other investigations. Altogether, 88 surface configurations are considered, grouped in four main divisions: tube banks, plate-fin surfaces, finned tube surfaces and screen and sphere matrix surfaces. The volume, covering work done during 1948 through the summer of 1954, was originally issued in 1954. It was copyrighted in 1955, but not published in book form until 1958.

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THE PHYSICS OF ELEMENTARY PARTICLES, by J. D. Jackson. 135 pages, diagrams, 6 × 9¼ in. Princeton, Princeton University Press, 1958. Price, $4.50.

Although this is an introductory treatment of the physics of elementary particles and their interactions, it is designed for graduate students and physicists not specializing in the field. The only prerequisite is a first course in quantum mechanics. The material is divided into three parts: The Interaction of Pions and Nucleons; *K*-Mesons and Hyperons; and Decay Processes. Since the text serves as an introduction, only the simplest fundamental processes are included.

THE AIR, by Edgar B. Schieldrop. 256 pages, illustrations, 6 × 9 in. New York, Philosophical Library, 1958. Price, $12.00.

This volume is the second in a series of four independent books on The Conquest of Space and Time. Fully illustrated with dozens of photographs that depict the birth of flight from the first balloon to a 400 miles per hour aeroplane. The study of aerodynamics shows the causes of failure and reveals the basic principles of flight in heavier-than-air machines. The development of world air transport and the attainment of stratosphere travel and supersonic speeds are covered, along with a revealing glimpse into the future.

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**Satellite "Post Office" System Proposed.**—An Earth satellite "post office" system that would handle all first class and air mail letter traffic between the United States and Europe at lower cost and substantially greater average speed than present services was proposed to the American Rocket Society at its annual meeting by Sidney Metzger, an engineer of the Radio Corporation of America.

According to Mr. Metzger, the proposed system, based on preliminary studies at the RCA Astro-Electronic Products Division, would employ standard letter forms reminiscent of the V-Mail used during World War II. At major post offices, the contents of these letters would be electronically converted to microwave radio signals and transmitted to a special ground station for relay to a similar station across the ocean by means of a satellite repeating station fixed in space thousands of miles above the earth at a longitude midway between the two continents. From the receiving station, the signals would be transmitted to the appropriate post office for electronic re-conversion to letter form for delivery to the addressees.

The use of such a system, Mr. Metzger said, could result in greater speed of delivery to all points at lower cost per letter than by present international air mail service. He stated that a rough analysis indicates a cost of 12 to 15 cents per letter and a maximum of two to two-and-one-half days from initial mailing to final delivery by means of the satellite system and local postal services requiring one day at each end. By contrast, he pointed out that present first class overseas mail by ship costs 8 cents for the first ounce and 5 cents for each additional ounce, and takes about ten days for delivery. Air mail between the United States and Europe costs at least 15 cents per letter and may take four to six days for delivery in most regions, although it may be less in the case of major cities.

Discussing the concept of the satellite "post office" system, Mr. Metzger said:

"A satellite at an altitude of thousands, or even hundreds, of miles above the Earth can provide line-of-sight paths between cities separated by thousands of miles. These paths permit the use of microwave frequencies—from 1,000 to 10,000 megacycles—and their attendant wide bandwidths, capable of handling a television program, or a thousand speech circuits, or a high speed facsimile signal which can be converted into print at a rate of 600 pages per minute."

One method for achieving the relay across the ocean, he said, would be the placing of a single repeater satellite in an equatorial orbit at an altitude of about 22,000 miles, where the satellite would travel at a speed which would keep it always above the same spot on the Earth. Equipped for its relay task with appropriate low-power receivers, amplifiers and transmitter, the satellite would weigh "several hundred pounds and could be launched by an Atlas or Titan plus upper stages," he added.

With the use of such a satellite, the basic operation of the system would then be handled in the following way, according to Mr. Metzger:



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"There would be one station in the United States and one in Europe which would communicate via the satellite repeater. Each of these two 'ground radio stations' would be connected to the twenty-five major post offices on its continent by a two-way 5-megacycle circuit provided by existing types of facilities, such as radio relay links or coaxial lines as are now used for television transmission. This would comprise a gigantic party line, with all stations on each continent linked across each of the two circuits—one for each direction of transmission.

"Each of the major post offices would have equipment for converting letter copy into electrical signals and vice versa. Transatlantic mail would be written on a special sheet of paper of standard typewriter size, carrying along one edge the names of the major European (or American) post offices. The sender would mark the major post office nearest to the letter's destination. The sheet also would have a gummed edge so that it could be sealed without an envelope, in a manner similar to wartime V-Mail letters.

"From the local post office, these letters would go to the nearest major post office, where they would be opened and placed in a scanning device for conversion into electrical signals and simultaneous transmission through the 'party line' circuit, over the satellite relay, and through the 'party line' on the other side of the ocean. Here the signals would be routed automatically to the appropriate major post office, where they would automatically be converted into hard copy, folded, sealed and delivered through the usual channels."

The post office equipment for the satellite system would be based upon known electronic techniques. For conversion of the written letters into electrical signals for transmission, Mr. Metzger suggested the use of a system similar to the "Ultrafax" high-speed facsimile developed by RCA and demonstrated about ten years ago. This system employs a combination of photographic and television techniques capable of handling 480 or more pages per minute. For the reconversion of the signals into letter form at the receiving post office, he proposed the use of the RCA "Electrofax" electronic printing process in combination with a special thin-window display tube now under development at RCA Laboratories for high-speed printing directly onto "Electrofax" paper.

**Ultrasonic Brazing.**—Aeroprojects Incorporated, of West Chester, Pa., pioneer firm in the field of ultrasonic joining, has designed Sonobraze equipment for brazing of aluminum and other materials with a melting temperature below about 1250 F. Several models of Sonobraze equipment are available, including gas-fired and electrically heated types. Although the process is particularly useful to join two insulated aluminum (or copper) wires without removal of the insulation, it is equally successful on aluminum sheet, sand and die castings, extrusions, tubing and bus bars. The easily operated Sonobraze units require from 1 to 10 seconds for the brazing process.

There are many advantages to be derived by using ultrasonic brazing: the surfaces do not have to be cleaned, either before or after; there is no flux, which is an important consideration when corrosion must be avoided; and the equipment is easy to operate.

Ultrasonic Sonobraze generators operate on 115 or 230-volt, 60-cycle alternating current. The standard

models are supplied in 25 and 110 r-f watt size, but for special industrial work, generators are available with 300, 600 and 2000 r-f watt outputs.

In the Sonobraze process, the generator supplies high-frequency current to a brazing head which converts the current to acoustical energy in the range of 15,000 to 60,000 cps. and then transmits this energy to the brazing tip. This tip removes the oxide coating on the material to be brazed and also helps the material to alloy with the base metal. Brazing heads utilize transducer-couplings which are cooled either by air or by water (or by both, in special cases).

This new fluxless brazing technique opens up possibilities for applications where flux joining is difficult or undesirable. Hand models, floor models and large industrial-type models can be supplied to meet particular requirements.

**Atom Blast Simulator Tests Materials.**—A unique device that permits engineers to test materials by subjecting them to the explosive force of an atomic bomb, but without the use of any radioactive materials, was described at the annual meeting of The American Society of Mechanical Engineers.

Located at the Naval Civil Engineering Laboratory at Port Hueneme, Calif., the unit consists of a 20-ton steel pressure vessel, roughly cylindrical in shape, mounted on top of a 75-ton heavily reinforced concrete pier. Engineers place the item to be tested, such as a beam, inside the steel shell. A firing tube, also contained in the shell is loaded with enough primacord explosive to produce the desired blast.

A description of the apparatus was contained in a paper presented by W. W. Boynton, director of Boynton Associates, of LaCanda, California, which designed the unit.

The test device is officially known as an Atomic Blast Simulator, but because of difficulties encountered in building it, workmen dubbed it the "Trojan Horse." Navy engineers refer to it, in honor of its creator, as the "Boyntonsaur."

The simulator can reach pressures of 20 to 185 psi. in from 1 to 2.3 milliseconds (thousandths of a second).

**Magnetometer for Space-Exploring Rockets.**—The discovery of a new type of magnetometer suitable for use in space-exploring rockets has been announced by a University of Michigan physicist. An extremely accurate device for determining the strength and characteristics of the Earth's magnetic field, it also could be useful in searching for oil and minerals.

Speaking at the Midwestern meeting of the American Physical Society, Dr. Peter A. Franken described the device as superior to other such instruments as it is more sensitive, compact, light, and rugged.

Franken stated that the new magnetometer differs markedly from past instruments in that it utilizes helium in a special gaseous state called metastable helium which makes possible a small and compact device. Other devices of comparable accuracy also require careful temperature control, but as the U-M magnetometer is temperature independent, the need for a weight-adding oven to maintain constant temperature is eliminated.

The magnetometer's sensitivity would be helpful in establishing the moon's magnetic field, Franken commented. The current belief is that this field may be some 10,000 times weaker than that of the Earth, he said.

The new light-weight device requires little power and could be sus-

pended under an airplane for mineral exploration. Small variations in the magnetic field which this magnetometer can measure serve as indications to geologists of the presence of oil or mineral deposits.

Franken explained that the magnetometer is operated with a technique that is known as optical pumping. A beam of light is shone through the helium to line up the helium atoms with the Earth's magnetic field, just as compass needles might be lined up. Then the atoms are exposed to various radio frequencies until forced to realign themselves. The frequency at which this occurs can be used as an indication of the Earth's magnetic field strength at that geographical point.

**Flight Test Equipment for Jet Airliners.**—Development of the first commercial high speed air-to-ground telemetry system for operation in the newly assigned 1345–1465 mc microwave telemetry band has been announced by Philco Corporation and Consolidated Electrodynamics Corporation. The radio frequency equipment was designed and built by Philco's Western Development Laboratories, Palo Alto, Calif., and is part of an airborne digital data-handling system which CEC developed for the Douglas Aircraft Company. First use of the equipment will be on the DC-8 flight test program. An initial system has been delivered and is presently undergoing preliminary flight tests.

With this new system, vast amounts of vital flight test data, such as engine performance, airframe stress, etc., are instantly relayed to the ground where they can be evaluated more effectively and economically.

Built to meet environmental requirements, the compact, airborne transmitter has sufficient power output to operate at a range of 100 miles from an altitude of 5000 ft. Greater ranges are expected from the normal operating altitude of jet aircraft. The transmitter uses frequency multiplier circuits and tuned coaxial cavities to produce output power in excess of 20 watts at any frequency within the band.

The FM superheterodyne receiver has an oscillator stability of $\pm.002$ per cent with an over-all noise figure of 8 db. The use of an auxilliary converter permits operation from either 115 volt 60 cycle or 115 volt 3 phase 400 cycle power.

The receiver has been installed in a mobile ground control record station housed in an air-conditioned trailer. A remotely controlled tracking antenna, similar to those used for radar equipment, is mounted on another trailer.

**Automatic Library.**—New machines to help make possible the "automatic library" of the future were recently demonstrated in Washington by International Business Machines Corporation. The new processes, when perfected, will provide answers to serious communication bottlenecks facing science, business and industry. Eventually, vast quantities of data—on subjects ranging from botany to rocketry—will be automatically read, summarized, coded, distributed, and filed by machines. Business as well as scientific information will flow through the automatic information systems of the future.

As a demonstration of automatic library techniques, abstracts of scientific papers were prepared automatically by an IBM 704 data processing system at the company's Vanguard Computing Center. An abstract, usually written by a specialist, is a

brief summary of a technical article, and is important to scientists in determining whether a particular paper is of value to them. The 704 analyzes articles word by word, selects the most significant sentences, and reproduces them on a printer.

Known as "auto-abstracting," the new process is a promising development in the area of information retrieval. Present abstracting methods are slow and subject to error, and are inadequate to cope with today's flow of technical literature. Also, the auto-abstract is a source of key words which pinpoint significant items in a document and form the basis of various automatic coding and indexing systems.

Auto-abstracts will in many cases become a by-product of the actual publication of technical papers, which are set in type by means of a punched paper tape containing the text. These tapes are converted to punched cards which serve as input to the computer for the auto-abstracting process. IBM researchers are presently at work on eliminating the card stage to speed the process further.

Data processing systems can also scan through the index of a huge technical literature collection to locate all references on a certain subject. Requesting scientists receive automatically printed bibliographies complete with abstracts for each document listed.

The new IBM Special Index Analyzer provides fast, accurate, and automatic reference to catalogued data. By continuous, automatic comparison of reference terms filed on punched cards, the machine supplies the inquirer with a list of references which combine all the material in the library dealing with specified subjects. Reference terms for an article on the fall of the Sputnik rocket, for example, are: atmosphere, drag, orbit, rocket, and satellite. The Special Index Analyzer is particularly adaptable to specialized libraries.

Other applications of IBM equipment in the new field of information retrieval have included indexing and reconstruction of missing passages of the Dead Sea Scrolls, and finding new uses for some of the three-quarters of a million chemical compounds now known to exist.

Future possibilities include a machine communication system with profiles showing the current information interests of persons and departments within an organization. By referring to the profiles, new incoming information would be automatically channeled to points where it would be most useful. The profiles would be revised to reflect each acceptance or rejection of new information and also new information requests, thus providing a feedback mechanism to adjust the system for changing interests.

Much research remains to be done to perfect and integrate the new automatic information systems, but IBM scientists foresee the time when libraries will be linked in a vast communications network serving the professional reader. By electronic means, a researcher could automatically gain access to information wherever it existed within this wide network.